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(71) Applicant (for all designated States except GB, IE, JP, KR, US): CARL ZEISS [DE/DE]; D-89518 Heidenheim (DE).

(71) Applicant (for GB, IE, JP, KR only): CARL-ZEISS-STIFTUNG trading as CARL ZEISS [DE/DE]; D-89518 Heidenheim (DE).

(72) Inventors; and

(75) Inventors/Applicants (for US only): ANTONI, Martin [DE/DE]; Brunnenstrasse 19, D-73430 Aalen (DE).

ESCUDERO-SANZ, Isabel [ES/NL]; Sytwinde 15, NL-2631 GP Nootdorp (NL). SINGER, Wolfgang [DE/DE]; Egerlandstrasse 45, D-73431 Aalen (DE). WANGLER, Johannes [DE/DE]; An der Reute 15, D-89551 Königsbronn (DE). SCHULTZ, Jörg [DE/DE]; Bohlstrasse 29, D-73430 Aalen (DE).

(74) Agent: DR. WEITZEL & PARTNER; Friedenstrasse 10, D-89522 Heidenheim (DE).

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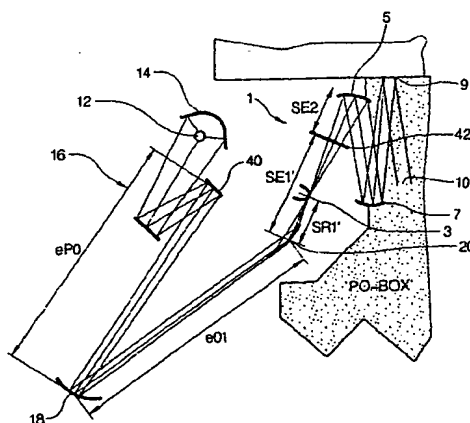
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(54) Title: MULTI MIRROR SYSTEM FOR AN ILLUMINATION SYSTEM



(57) Abstract: The invention relates to a multi-mirror-system for an illumination system, especially for lithography with wavelengths  $\leq 193$  nm comprising an imaging system, wherein said imaging system comprises at least a first mirror and a second mirror, an object plane, an image plane, wherein the imaging system forms an image of the object, an arc-shaped field in said image plane, whereby the radial direction of in the middle the arc-shaped field defines a scanning direction. The multi-mirror-system is characterized in that at least said first mirror and said second mirror of said imaging system are arranged in the optical path of the imaging system in such a position and having such a shape, that the edge sharpness of the arc-shaped field in the image plane is smaller than 5 mm, preferably 2 mm, most preferably 1 mm in scanning direction.

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## Multi Mirror System for an Illumination System

The invention relates to a multi-mirror-system for an illumination system,  
5 especially for lithography with wavelengths  $\leq 193$  nm comprising an  
imaging system.

EUV-lithography constitutes one of the most promising candidates for next  
generation lithography. The evolution of semiconductor fabrication demands  
10 reduced feature sizes of 50 nm and beyond. This resolution is obtained by  
the application of a short wavelength of 13.5 nm and moderate numerical  
apertures of 0.2 to 0.3. The image quality of the lithography system is  
determined by the projection optics as well as by the performance of the  
illumination system. Illumination system design is one of the key challenges  
15 of EUV lithography. In today's lithographic systems, the illuminator has to  
deliver invariant illumination across the reticle field. For EUV, several  
additional requirements have to be addressed.

EUV imaging systems need to be realized as reflective optical systems. For  
20 this reason, an unobscured pupil and a highly corrected image field can  
only be achieved in a small radial range of the image. Hence the field shape  
is a ring-field with high aspect ratio of typically 2 mm (width) x 22 - 26 mm  
(arc length) at wafer level. The projection systems operates in scanning  
mode.

EUV illumination systems will in general be non-centred systems formed by  
off-axis segments of aspherical mirrors. The reflectivity of multilayer-coated  
surfaces is approximately 70 % for normal incidence and 90 % for grazing  
incidence. In order to maximize throughput, the number of reflections has to  
30 be minimized and grazing incidence elements should be used whenever  
possible.

In order to achieve the requirements of the illumination system with a limited number of optical components, the complexity of the components has to be increased. Consequently, the surfaces will be segmented or aspherical. The shape and size of aspherical mirrors and segmented elements, together with stringent requirements for the surface quality put a major challenge on manufacturing these components.

Several EUV-light sources are currently being discussed. They differ in system aspects, but also in important illuminator-related aspects. System aspects are e.g. output power, repetition rate, footprint. For the illumination system size and divergence of the radiating plasma, radiation characteristics and geometrical vignetting are relevant. The illumination design has to account for these properties.

It is well known from basic physics that the étendue is invariant in optical systems. The étendue delivered by the source has to be smaller than the étendue of the illuminator, otherwise light will be lost. For current sources, however, the étendue is approximately one order of magnitude smaller, therefore either field or pupil of the optical system is not filled completely. In addition, the ring-field with high aspect ratio requires an anamorphic étendue, which has to be formed by the illuminator.

According to Helmholtz-Lagrange, the product of field  $A$  and numerical aperture  $NA$  is invariant in classical optical systems. For unobscured and circular pupils the Helmholtz-Lagrange-Invariant HLI or étendue can be written as:

$$(1) \quad \text{étendue} = A \cdot \pi \cdot NA^2$$

In general, the invariance of the étendue can be interpreted as the optical equivalent to the invariance of the phase space volume in conservative

systems. The étendue can be written as a volume integral in four dimensions,

$$(2) \quad \text{étendue} = \int F(x, y, P_x, P_y) dx dy dP_x dP_y$$

with the function F describing the occupied volume in phase space and

$$\bar{P} = (n \sin \theta \cos \varphi, n \sin \theta \sin \varphi, n \cos \theta)$$

the vector of optical direction cosines, which corresponds to the pupil coordinates.

For centred systems, the optical direction cosine integration in equation (2) can be written in polar coordinates  $(\theta, \varphi)$ :

$$(3) \quad \begin{aligned} \text{étendue} &= \int F(x, y, \theta, \varphi) dA \left| \frac{\partial(P_x, P_y)}{\partial(\theta, \varphi)} \right| d\theta d\varphi \\ &= \int F(x, y, \theta, \varphi) dA \sin \theta \cos \theta d\theta d\varphi \end{aligned}$$

The illumination field at the reticle is arc-shaped with dimensions of approx. 8 mm x 88 mm. Thus the étendue to be provided by the illumination system has to be almost isotropic in angular domain, but highly anamorphic in space domain with an aspect ratio of 1:10. The different light sources, however, show an almost isotropic behaviour in space as well as in angular domain. In addition, the étendue of all known light sources is too small, although an optimum collection efficiency is assumed. In EUV illumination systems it is therefore essential to transform the étendue of the light source without changing the isotropy in angular domain. Array elements offer the

most promising methods to transform the étendue. With optical array elements the field formation with high aspect ratio as well as the filling of the required aperture can be achieved.

5 The étendue is not increased, but only transformed by the introduction of a segmentation in the entrance pupil. Examples for array elements are the ripple-plate (an array of cylindrical lenses) and the fly's eye-integrator. Both are capable of forming a field with high aspect ratio and introduce a segmentation in the entrance pupil. Partial coherent image simulations show  
10 that the influence of the segmentation of the pupil can be tolerated, as far as a reasonable number of segments is chosen. Illumination systems with fly's-eye integrator are described in DE 199 03 807 A1 and WO 99/57732, the content of said applications is incorporated herein by reference.

15 Illumination systems with ripple plates are known from Henry N. Chapman, Keith A. Nugent, "A novel Condensor for EUV Lithography Ring-Field Projection Optics", Proceedings of SPIE 3767, pp. 225 - 236, 1999.

The content of said article is also fully incorporated herein by reference.

20 The illumination system has to be combined with the lens system and it has to meet the constraints of the machine layout. The mechanical layout of non-centred reflective systems strongly depends on the number of mirrors and the folding angles. Within this setup, the mirrors and special  
25 components must be mounted with tight tolerances. Heat load and natural frequencies of the frame structure have to be considered.

In EUV, each reflection will suffer from 30 % light loss. The light is absorbed or dissipated leading to a heating of the mirrors. To avoid deformations of  
30 the optical elements as well as the mechanical structure, a cooling of mirrors is required. This is especially challenging because the complete optical

system has to be under vacuum and hence only conduction can be used for cooling.

Furthermore in an illumination system for lithography it is desirable to introduce means for cutting off the field e.g. by a field stop.

An illumination system for lithography with a field stop is shown in US-A-4 294 538. The content of said document is incorporated herein fully by reference. The system according to US-A-4 294 538 comprises a slit plate on which an arcuate image of the light source is formed. By varying the radial length and the length in direction of the circular arc of the opening of the slit it is possible to adjust the radial length and the length in the direction of the circular arc of the arcuate image of the light source on a mask. Therefore the slit plate can also be designated as a field stop. Between the slit plate and the mask there are two mirrors arranged for imaging the arc-shaped field in the plane of the slit plate onto a reticle-mask.

Since the illumination system known from US-A-4 294 538 is designed for a light source comprising a ultra high tension mercury lamp emitting light in the visible region the system is totally different to a illumination system for wavelengths  $\leq 193$  nm.

For example said system has no means for enhancing the étendue of the light source e.g. by raster elements of a fly's-eye integrator, which is essential for EUV-systems.

The mirrors according to US-A-4 294 538 are impinged by the rays travelling through the system under an angle of  $45^\circ$ , which is not possible in EUV-systems, since normal incidence mirrors in EUV-systems are comprising more than 40 pairs of alternating layers. A large number of alternating layers leads to phase effects if the mean angle of incidence becomes more than

30° or is lower than 70° . Using an angle of incidence of 45° in an EUV-system as in the state of the art would lead to a total separation of s- and p-polarisation and one of both polarisation is lost completely according to Brewster law. Furthermore such a mirror would function as a polarizing element.

Another disadvantage of the system according to US 4 294 538 are the rays impinging the reticle in the object plane telecentric, which is not possible in EUV-systems using a reflection mask.

Furthermore the system known from US-A-4 294 538 is a 1:1 system. This means that the field stop in the object plane of the imaging System has the same size as the field in the image plane. Therefore the field stop has always to be moved with the same velocity as the reticle in the image plane. Furthermore said illumination system should be applicable in high throughput systems working with much higher velocities of reticle and mask than conventional systems e.g. systems known from US-A-4 294 538.

Object of the invention is to provide an imaging system imaging an object, e.g. a field stop into an image, e.g. a reticle-mask for an illumination system for lithography with wavelengths  $\leq 193$  nm. Especially losses should be minimized, while the quality of the image especially regarding edge sharpness in scanning direction should be as high as possible.

Said object of the invention is solved in a first embodiment by a multi-mirror-system comprising an imaging system with at least a first and a second mirror, whereby said first mirror and said second mirror are arranged in the optical path of the imaging system in such a position and having such a shape, that the edge sharpness of the arc-shaped field in the image plane is smaller than 5 mm, preferably 2 mm, most preferably 1 mm in scanning direction.

In an advantageous embodiment the edge sharpness of the arc-shaped field in the image plane is smaller than 5 mm, preferably 2 mm, most preferably 1 mm also in the direction perpendicular to the scanning direction.

- 5 While the field in the image plane is always arc-shaped, in an first embodiment of the invention the object in the object plane is also an arc-shaped field; which means that the inventive imaging system is not comprising any field forming components.
- 10 Advantageously the rays travelling from the object plane to the image plane in the imaging system are impinging the first and the second mirror defining a first and a second used area on the mirrors, whereby the rays are impinging the first and the second mirror in the used area with an incidence angle relative to the surface normal of the mirror  $\leq 30^\circ$  or  $\geq 60^\circ$ , especially  $\leq$
- 15  $20^\circ$  or  $\geq 70^\circ$ , in order to minimize light losses in the system. To move the field stop in the object plane and the reticle in the image plane of the imaging system with different velocities the magnification ratio of the imaging system is unequal to 1.
- 20 In a preferred embodiment the inventive imaging system is a non centred system.
- Advantageously an aperture stop is located on or close to the plane conjugate to the exit pupil of the imaging system.
- 25 Preferably the first and/or the second mirror of the imaging system is an aspheric mirror.
- 30 In a preferred embodiment of the invention the first mirror is a concave mirror having a nearly hyperbolic form or a nearly elliptic form and is defining a first axis of rotation.



Furthermore also the second mirror is a concave mirror having a nearly hyperbolic form or a nearly elliptic form and is defining a second axis of rotation.

5 Preferably the first and the second mirror are comprising a used area in which the rays travelling through the imaging system are impinging the first and the second mirror; the used area is arranged off-axis in respect to the first and second axis of rotation.

10 In advantageous embodiment the first axis of rotation and the second axis of rotation subtend an angle  $\gamma$ . Said angle  $\gamma$  is calculated from a COMA-correction of the system. The first mirror and the second mirror are defining a first magnification for the chief ray travelling through the centre of the field and the centre of the exit pupil, a second magnification for the upper COMA ray travelling through the centre of the field and the upper edge of the exit pupil and a third magnification for the lower COMA ray travelling through the  
15 centre of the field and the lower edge of the exit pupil. If the system is COMA corrected the first, the second and the third magnification are nearly identical. Said condition defines the angle  $\gamma$  between the first and the  
20 second axis of rotation.

In an second embodiment of the invention a multi-mirror-system for an illumination system with wavelengths  $\leq 193$  nm is comprising an imaging system, whereby said imaging system comprises at least a first mirror and a  
25 field forming optical component. In such an embodiment of the invention the field in the object plane can be of arbitrary shape, e.g. a rectangular field.

In case of a rectangular field the rectangular field is formed into an arc-shaped field in the image plane by the field forming optical component of  
30 the imaging system. The advantage of the second embodiment of the invention is the fact, that no extra optical components for forming the field in

the light path arranged before the inventive multi-mirror-system are necessary. This reduces the total number of mirrors in the illumination system and therefore the losses within the illumination system.

5 Preferably the aforementioned field forming component of the second embodiment comprises at least one grazing incidence mirror. Grazing incidence mirrors have the advantage that they must not be coated, whereas normal incidence mirrors in the EUV-range are always multilayer systems with high losses.

10

In a preferred embodiment the field forming component comprises two mirrors, a first grazing incidence mirror with positive optical power and a second grazing incidence mirror for rotating the field.

15 Another preferred embodiment employs a single grazing incidence field lens with negative optical power to achieve an arc-shaped field with the desired orientation.

20 Apart from the imaging system the invention provides an illumination system, especially for lithography with wavelengths  $\leq 193$  nm with a light source, a multi-mirror system comprising an imaging system, whereby the imaging system comprises an object plane. The illumination system further comprises an optical component for forming an arc-shaped field in the object plane of the multi-mirror-system, in the light path arranged before the  
25 multi-mirror system. The multi-mirror-system is a system according to the invention for imaging the field from the object plane into the image plane of the imaging system.

30 To enhance the étendue said illumination system could comprise at least one mirror or one lens which is or which are comprising raster elements for forming secondary light sources.

The aforementioned illumination system could be used in an EUV projection exposure unit comprising a mask on a carrier system, said mask being positioned in the image plane of the imaging system, a projection objective with an entrance pupil, said entrance pupil is situated in the same plane as the exit pupil of the illumination system and a light sensitive object on a carrier system.

Preferred embodiments of the invention are described with regard to the following figures.

In the figures are shown:

figure 1 and

figure 2: complete illumination system with an imaging system according to the invention and an arc-shaped field in the object plane of the imaging system

figure 3: a schematic view of the inventive illumination system

figures 4

to 7: schematic views of the inventive illumination system with abbreviation used for the derivation of the COMA correction of the system

figure 8: detailed view of a COMA-corrected system

figure 8.1: arc-shaped field in the image plane

figures 8.2

and 8.3: spot diagrams of the system according to figure 8 in the image plane

figure 9: detailed view of a system with correction of COMA, astigmatism and spherical aberration and a magnification of -1.0

figures 9.1

- to 9.2: spot diagrams of the system according to figure 9 in the image plane
- figure 10: detailed view of a system with correction of COMA, astigmatism and spherical aberration of -0.85
- 5 figure 10.1
- to 10.2: spot diagrams of the system according to figure 10 in the image plane
- figure 11: EUV-illumination system with an inventive imaging system and a ripple plate as field forming component
- 10 figure 12: detailed view of a COMA corrected imaging system with a magnification  $\beta = -1.5$
- figures 12.1
- to 12.2: spot diagram of a system according to figure 12 in the image plane
- 15 figure 13: detailed view of an imaging system with a magnification  $\beta = -1.5$  and correction of COMA, astigmatism and spherical aberration
- figures 13.1
- to 13.2: spot diagram of a system according to figure 13 in the image plane
- 20 figure 14: schematic view of an imaging system comprising a normal and a grazing incidence mirror as field forming component
- figure 15: schematic view of an imaging system comprising two normal and a grazing incidence mirror as field forming component
- 25 figure 16: view of the field in the object- and the image plane with field stop or REMA-blades
- figure 17: detailed view of a system according to figure 15
- figure 17.1: spot diagram of a system according to figure 17
- figure 18: detailed view of a system according to figure 16
- 30 figure 18.1: spot diagram of a system according to figure 18

In figure 1 an EUV-illumination system comprising an inventive imaging system 1 comprising an object plane 3, a first mirror 5, a second mirror 7 and an image plane 9 is shown. In the object plane 3 the field stop of the system is located. Furthermore the field in the object plane 3 is already arc-shaped. The imaging system 1 images the arc-shaped field from the object plane 3 into the image plane 9. In the image plane 9 the reticle or mask of the EUV-illumination system is located. Also shown is the exit pupil 10 of the imaging system 1, which is identical with the exit pupil of the total EUV-illumination system. The exit pupil 10 falls together with the entrance pupil of the projection optical system. Furthermore the EUV-illumination system shown in Figure 1 comprises a light source 12, a collector 14, means 16 for enhancing the étendue of the light source 12 and field forming mirrors 18, 20 for forming the arc-shaped field in the object plane 3 of the imaging system 1. Also shown are a first plane 40 conjugate to the exit pupil 10 and a second plane 42 conjugate to the exit pupil 10. Furthermore the distance  $e_{P0}$  between first field forming mirror 18 and the first plane 40 conjugated to the exit pupil 10, the distance  $e_{01}$  between the first 18 and the second 20 field forming mirror, the distance  $SE1'$  between the second field forming mirror 20 and the second plane 42 conjugate to the exit pupil 10, the distance  $SR1'$  between the second field forming mirror 20 and the object plane 3 and the distance  $SE2$  between the second plane 42 conjugate to the exit pupil 10 and the first imaging mirror 5 is depicted.

Throughout the system examples shown hereinafter some parameters remain constant. The design principles as shown below however, can also be applied to other sets of parameters.

In all embodiments shown in this application the incidence angle at the image plane 9 of the imaging system is  $6^\circ$  and the numerical aperture at the image plane 9 is  $NA = 0.05$ . It corresponds for example to a  $NA = 0.0625$  of the projection lens and a  $\sigma = 0.8$ . The projection lens arranged in the

light path after the EUV-illumination system has typically a 4x-magnification and thus  $NA = 0.25$  at the light sensitive object e.g. the wafer of the EUV-projection exposure unit.

5 Figure 2 shows the EUV-illumination system depicted schematic in figure 1 in greater detail. Same components as in figure 1 are designated with the same reference numbers.

10 The system according to figure 2 comprises a light source 12 and a collector-mirror 14. Regarding the possible EUV-light sources reference is made to DE 199 038 07 A1 and WO 99/57732, the content of said documents is incorporated herein by reference. The collector mirror 14 of the system according to figure 2 is of elliptical shape. The means 16 for enhancing the étendue comprises two mirrors with raster elements 30, 32 so called fly-eyes integrators. The first mirror with raster elements 30 comprises an array of 4 x 64 field facets; each field facet being of plane or elliptical, toroidal or spherical shape ( $R \approx -850$  mm). The second mirror with raster elements 32 comprises an array of 16 x 16 pupil facets or a spherical or hexagonal grid with pupil facets, each pupil facet being of hyperbolic, toroidal or spherical shape ( $R \approx -960$  mm). The second mirror 32 is located in a plane conjugate to the exit pupil 10 of the illumination system.

25 An illumination system with a first and a second mirror comprising raster elements as described before is known from DE 199 038 07 A1 and WO 99/57732; the content of said applications is incorporated herein by reference.

30 For forming the arc shaped field in the object plane of the imaging system comprises two field forming mirrors 18, 20. The second field forming mirror 20 is a grazing incidence mirror.

In principle one mirror, here the mirror 20, would be sufficient for field forming. But mirror 18 is required to control the length of the system and the size of the pupil facets. In order to achieve a large field radius of  $\approx 100$  mm mirror 20 must have low optical power.

5

The size of the field and the pupil facets are related to the étendue of the system. The product of the size of the field facets and the size of the pupil plane is determined by the étendue. The pupil plane is a first plane 40 conjugate to the exit pupil 10 of the illumination system. In said plane the second mirror with raster elements 32 is located. Due to the aforementioned relation restrictions to the size of the field facets and the pupil facets are given. If the magnification for the pupil facets is very large, i.e. the pupil facet is very small, field facets become very large. To avoid large magnification of the imaging of the pupil facets into a second plane 42 conjugate to the exit pupil 10 of the system either the distance between mirror 20 and the second mirror with raster elements 32 increases or an additional mirror 18 has to be introduced. The first field forming mirror 18 has almost all power of the imaging system consisting of a first field forming mirror 18 and a second mirror 20 for imaging the pupil facets of the second field forming mirror with raster elements 32 into the second plane 42 conjugate to the exit pupil 10 of the system.

10  
15  
20

The data for the first field mirror 18 and the second field mirror 20 are given in table 1:

25

Table 1:

Data for the first and the second field mirror

	first field mirror 18	second field mirror 20
shape	hyperbola	ellipsoid
f	$\approx 1616$ mm	$\approx 605$ mm
incidence angle versus surface normal	$7^\circ$	$75^\circ$ (grazing incidence)
conic section layout	for pupil imaging	for pupil imaging
$\beta_{\text{pupil imaging}}$	7.46429	-0.05386

The magnification between the first plane 40 conjugate to the exit pupil 10 and the second plane 42 conjugate to exit pupil 10 is  $\beta_{40-42} \approx -0.4$ . The field radius of the arc-shaped field in the object plane 3 is controlled by the second field mirror 20.

If the magnification  $\beta_{\text{image}} = -1$  of the imaging system and  $R_{\text{Field}} = 100$  mm the field radius to be formed by the second field forming mirror 20 is  $R_{\text{Obj}} = -100$  mm. There are three means to control the radius  $R_{\text{Obj}}$ : The optical power, see table 1,

$f \approx 605$  mm, the chief ray distance between the second field forming mirror 20 and the object plane 3:

$SR1' \approx 250$  mm and the grazing incidence angle.

With the further values for the system layout

$eP0 = 1400$  mm

$e01 = 1550$  mm

$SE1' \approx 637$  mm

$SE2 \approx -262.965$  mm



the system can be derived with first order optical formulas.

In the second plane 42 conjugate to the exit pupil 10 an accessible aperture stop for the illumination system could be located.

5

Also shown in figure 2 is the inventive multi-mirror-system comprising an imaging system 1 with a first 5 and a second 7 imaging mirror for imaging the arc-shaped field from the object plane 3, which is conjugate to the field plane, into the image plane 9, which corresponds to the field plane of the illumination system and in which the reticle or mask of the illumination system is located.

10

The conjugate field plane 3 could be used as a plane for reticle masking. Said plane is located near to the second field forming mirror 20 at the limit for construction, e.g.  $SR' \approx 250$  mm chief ray distance for  $\approx 15^\circ$  grazing incidence reflection on the mirror. The field in the conjugate field plane which is the object plane 3 is arc-shaped by field forming mirror 20, thus rema blades need to be almost rectangular. Small distortions of a following rema system can be compensated for.

15

20

Since all mirrors of the illumination system have positive optical power, the field orientation in the conjugate field plane 3 after positive mirror 20 is mirrored by negative magnification of the inventive imaging system 1. The field orientation in the field plane 9 is then correct.

25

Since the second field forming mirror 20 is off-axis in order to compensate the distortion due to this off-axis arrangement, the pupil facets have to be arranged on the second mirror with raster elements 32 on a distorted grid.

30

With pupil facets arranged on a pre-distorted grid optimized pupils with respect to telecentricity and ellipticity can be achieved.

The derivation of a multi-mirror-system comprising an imaging system for imaging a REMA-blade situated in the object-plane or REMA-plane 3 of the inventive multi-mirror-system into the image plane or field plane 9, wherein the reticle is situated will be described in detail hereinbelow.

5

Figure 3 shows in a schematic refractive view the elements of the inventive imaging system and abbreviations used in table 1. Furthermore components with reference numbers used in figure 1 and 2 are designated with the same reference numbers. Furthermore in figure 3 is shown the virtual image 3' of the field plane and the virtual image 10' of the exit pupil.

10

The imaging system according to figure 3 and table 2 is a hyperbolic-ellipsoid combination as a first order starting system. The data of the first order system are given in table 2.

15

Table 2:

First order system layout

	first imaging mirror 5	Hyperboloid	second imaging mirror 7	Ellipsoid
5		field imaging		pupil imaging
		e23	650.0	
	f	768.1818	f	650.0
	Pupil imaging			
	SE2	-262.9651	SE3	-1049.8383
10	SE2'	-399.8383	SE3'	1706.6772
	$\beta_2$	1.5205	$\beta_3$	-1.6257
	Field imaging			
	SR2	-650.0	SR3	-4875.0
	SR2'	-4225.0	SR3'	750.0
15	$\beta_2$	6.5	$\beta_3$	-0.15385

For the results of table 2, well-known first-order lens-formulas were used, e.g.

$$\begin{aligned}
 (4) \quad & \beta = S'/S \\
 & S_{i+1} = S_i - e_{i,i+1} \\
 & f = 1/(1/S' - 1/S) \quad (\text{"lens-maker"-equation})
 \end{aligned}$$

where S and S' stands for SE and SE' or SR and SR', respectively.

In the next step designing an imaging system according to the invention the first order system shown in table 2 is optimized and COMA corrected.

The first mirror 5 of the imaging system is a hyperbolic mirror, optimized for field imaging, which means imaging of the field in the REMA plane 3 into the

field plane 9. The second mirror 7 of the imaging systems is an elliptical mirror optimized for pupil imaging, which means imaging of the second plane 42 conjugate to the exit pupil into the exit pupil 10. The overall system comprising the first 5 and the second 7 imaging mirror with abbreviations used in table 3 for the COMA corrected system is shown in figures 3 to 5. Identical components as in figure 1, figure 2 and figure 3 are designated with the same reference numbers.

Apart from the elements already shown in figures 1 and 2 in figure 3; figure 4 shows:

- the axis of rotation 50 of the first imaging mirror 5
- the axis of rotation 52 of the second imaging mirror 7
- the centre 54 of the first imaging mirror
- the vertex of the first imaging mirror 56
- the virtual image 3' of the field plane 3
- the centre 58 of the second imaging mirror
- the vertex of the second imaging mirror 60
- the virtual image 10' of the exit pupil 10 of the illumination system
- the chief ray 62

As is apparent from figure 4 the axis 50 of the hyperbolic mirror 5 and the axis of the elliptic mirror 7 subtend an angle  $\gamma$ .

Figure 5 shows in detail the first imaging mirror 5, which is in this embodiment a hyperboloid, of the inventive imaging system according to figure 4 and figure 6 the second imaging mirror 7 of the imaging system according to figure 4, which in this embodiment is an ellipse. The same elements as in figure 4 are designated in figure 5 and figure 6 with the same reference numbers.

In figure 5 depicting the first hyperbolic mirror 5 the abbreviation used for the following equations calculating the parameters of the hyperbola are known:

5 With positive angles  $\omega_2$  and  $\delta_2$  follows

$$(5) \quad d_2 = -SR2 \cdot \sin(\omega_2) = -SR2' \cdot \sin(\delta_2)$$

$$10 \quad (6) \quad \omega_2 = 2\alpha_2 - \delta_2$$

$$\Rightarrow (7) \quad \beta_{field} = \frac{SR2}{SR2'} = \frac{\sin(2\alpha_2 - \delta_2)}{\sin(\delta_2)} = \frac{\sin(2\alpha_2)}{\tan(\delta_2)} - \cos(2\alpha_2)$$

$$\Rightarrow (8) \quad \delta_2 = \arctan \left( \frac{\sin(2\alpha_2)}{\beta_{field} + \cos(2\alpha_2)} \right)$$

20 Then the angle between incident chief ray and hyperbola axis is:

$$\omega_2 = 2\alpha_2 - \delta_2$$

Hyperbola equation:

$$25 \quad (9) \quad \frac{z^2}{a^2} - \frac{d^2}{b^2} = 1; \quad a = \sqrt{e^2 - b^2}$$

insertion and solution for  $b^2$  gives:

$$(10) \quad b^4 + (z^2 + d^2 - e^2) b^2 - d^2 e^2 = 0$$

5

$$\Rightarrow (11) \quad b^2 = \frac{-(z^2 + d^2 - e^2) + \sqrt{(z^2 + d^2 - e^2)^2 - 4 d^2 e^2}}{2}$$

10

with equation (5) and

$$(12a) \quad z_2 = e + SR2 \cdot \cos(\omega_2)$$

15

$$(12b) \quad e = \frac{(-SR2 \cdot \cos(\omega_2) - SR2' \cdot \cos(\delta_2))}{2}$$

the parameters defining the hyperbola can be calculated.

20

In figure 6 depicting the second elliptic mirror 7 the abbreviations used for the following equations calculating the parameters of the ellipse are shown:

With positive angles  $\omega_3$  and  $\delta_3$  follows

25

$$(13) \quad d_3 = -SE3 \cdot \sin(\omega_3) = +SE3' \cdot \sin(\delta_3)$$

$$(14) \quad \omega_3 = 2\alpha_3 + \delta_3$$

30

$$\Rightarrow (15) \quad -\beta_{pupil} = \frac{SE3'}{-SE3} = \frac{\sin(2\alpha_3 + \delta_3)}{\sin(\delta_3)} = \frac{\sin(2\alpha_3)}{\tan(\delta_3)} + \cos(2\alpha_3)$$

$$\Rightarrow (16) \quad \delta_3 = \arctan \left( \frac{-\sin (2\alpha_3)}{\beta_{field} + \cos (2\alpha_3)} \right)$$

5

The angle between incident chief ray and the hyperbola axis is defined by equation (14).

Ellipsoid equation:

10

$$(17) \quad \frac{z^2}{a^2} + \frac{d^2}{b^2} = 1; \quad a = \sqrt{e^2 + b^2}$$

insertion and solution for  $b^2$  gives:

15

$$(18) \quad b^4 + (e^2 - z^2 - d^2) b^2 - d^2 e^2 = 0$$

$$\Rightarrow (19) \quad b^2 = \frac{-(e^2 - z^2 - d^2) + \sqrt{(e^2 - z^2 - d^2)^2 - 4d^2 e^2}}{2}$$

20

with equation (13) and

$$(20a) \quad z_3 = e - SE2 \cdot \cos (\omega_3)$$

25

$$(20b) \quad e = \frac{(SE3 \cdot \cos (\omega_3) + SE3' \cdot \cos (\delta_3))}{2}$$

the parameters defining the ellipsoid can be calculated.

Furthermore for ellipse and hyperbola following equations are well known:

$$(21) \quad \rho = \frac{b^2}{a} \quad \text{curvature at node R} = -p$$

$$(22) \quad \varepsilon = \frac{e}{a} \quad \text{eccentricity}$$

$$(23) \quad K = -\varepsilon^2 \quad \text{conic constant}$$

By COMA-correcting the first order system according to table 2 with an analytical calculation angle  $\gamma$  is determined. The COMA-correction uses for calculating  $\gamma$  the magnification of the imaging for the chief ray 62 and the coma-rays not shown in figure 4-6. The differences in magnifications can be reduced by minimization of the angle of incidence  $\alpha_3$  ( $7^\circ$ ) and corresponding selection of  $\alpha_2$ . In this example the equations are minimized by the gradient method, which means choose a start system e.g. according to table 2, calculate the magnifications, change the angle  $\alpha_2$  and calculate a new magnifications. From the difference in magnifications the next  $\alpha_2$  can be calculated. Repeat this algorithm until difference in magnification for the chief ray and the upper and lower COMA-ray is less than e.g. 0,5 %.

The COMA-correction will be described hereinbelow in detail with reference to figure 7. Identical elements as in figure 1 to 6 are designated with the same reference numbers. Furthermore in figure 7 is shown the lower COMA ray 70.

The calculation of the magnifications along the chief ray 62 is clear from the first order derivation.

The calculation for the COMA or rim rays is shown with regard to the lower COMA ray 70.



The COMA rays 70 for the imaging  $3 \rightarrow 3'$  at the hyperbola is straight forward. The COMA or rim rays in the object plane 3 can be defined by the angles between rays and hyperbola axis:

$$(24) \quad \omega_{2c} = \omega_2 \mp \arcsin \left( \left| NA_{reticle} \cdot \beta_{rema, field} \right| \right)$$

with  $\omega_2$  as shown in figure 5.

The distances between the image points 3 and  $3'$  and the intersection point  $l_{2c}$  of the mirror with the COMA or rim rays are given by hyperbola formulas in polar co-ordinates:

$$(25) \quad S_c = \overline{Rl_{2c}} = \frac{p}{1 + \varepsilon \cos(\omega_{2c})}$$

$$(26) \quad S'_c = \overline{l_{2c}R'} = S_c + 2a$$

$\alpha, \varepsilon, p$ : hyperbola parameters

To calculate the lengths at the ellipse is more complicated, because the COMA or rim rays will not intersect in the plane 9 any more. However the magnification can be calculated approximately after calculating the intersection point  $l_{3c}$ . With

$$(27) \quad \omega_{3c} = \delta_{2c} \pm \gamma$$

for given  $\gamma, \omega_{3c}$  and thus the intersection point  $l_{3c}$  can be calculated. With

$$(28) \quad L_c = \overline{R' l_{3c}}$$

$$(29) \quad L'_c = \overline{l_{3c} R''}$$

the magnification of the rema-imaging system for the rim or COMA rays follows

$$(30) \quad \beta_{c\pm} = \frac{L'_c}{L_c} \cdot \frac{S'_c}{S_c}$$

As shown in figure 7 this derivation is not exact, because the rim rays will not intersect in the image plane 9 exactly. However, magnification can be calculated with reasonable accuracy, sufficient for a minimisation of the COMA error.

An optimisation with the gradient method described before leads to the solution given in table 3.

Table 3:

COMA corrected system starting from the system according to table 1.

first imaging mirror 5		second imaging mirror 7	
Design parameters (abbreviation see figures 4 to 6)			
$\alpha_2$	16.328°	$\alpha_3$	7.0°
$\delta_2$	4.2034	$\delta_3$	20.26125
$\omega_2$	28.4526	$\omega_3$	34.26125
$d_2 = \text{YDE}$	309.6806	$d_3 = \text{YDE}$	591.0246
$z_2$	1821.0739	$z_3$	1234.3716
$a$	1787.5	$a$	1378.2578
$b$	1590.3439	$b$	1328.5797
$e$	2392.5614	$e$	366.7021
$R$	-1414.9336	$R$	-1280.6922
$\text{eps} = e/a$	1.3385	$\text{eps} = e/a$	0.2661
$K = -\text{eps}^2$	-1.7916	$K = -\text{eps}^2$	-0.0708
$\text{ZDE} = z_2 - a$	33.5616	$\text{ZDE} = a - z_3$	143.8861

YDE and ZDE are the y- and z-components of the decenter vector of the nearest vertex point of the conic section.

For a COMA-corrected system according to table 3 the magnification difference due to COMA is approx. 0.1 % and is identical for the upper and the lower COMA-ray. The data for the magnification  $\beta$  of the inventive two mirror imaging system for the chief ray, the upper and lower COMA-ray after COMA correction is shown in table 4.

Table 4:

Magnification  $\beta$  for chief ray, upper and lower COMA-ray

Coma-correction of Field imaging			
Upper COMA-ray		Chief ray	Lower COMA-ray
Magnification	1.0012	1.0000	1.0012

In figure 8 the COMA-corrected imaging system is shown. Identical elements as in figures 1 to 7 are designated with the same reference numbers.

In figure 8.1 the arc-shaped field in the field or reticle plane with cartesian coordinates x and y is shown. Reference number 100 designates a field point in the centre of the arc-shaped field and 102, a field point at the edge of the arc-shaped field. The y-axis denotes the scanning direction and the x-axis the direction perpendicular to the scanning direction.

In figure 8.2 the spot diagram for a field point 100 and in figure 8.3 the spot diagram for a field point 102 of a COMA-corrected multi-mirror-system according to figures 4 to 8 is depicted. The spot diagram is the diagram resulting from a multiplicity of rays travelling through the system with the aperture  $NA_{\text{object}}$  and impinging the field or reticle plane in a predetermined

field point, e.g. the centre of the field 100. The aperture is  $NA_{\text{object}} = 0.05$  in the system described in figures 4 to 8.

5 As is apparent from the spot-diagrams 8.2 and 8.3 the edge sharpness EDS in scanning direction, corresponding to the y-axis of the arc shaped field, in COMA corrected system is smaller than 2 mm.

10 The edge sharpness EDS of a system in scanning direction is defined as the difference of the points with the greatest value and the smallest value in y-direction for an edge field point, e.g. edge field point 102 as shown in figure 8.3.

15 For further optimizing the inventive imaging system astigmatism and spherical aberration has to be considered. Nevertheless a balanced system can be found with only hyperbolic and elliptical mirrors. Figure 9 and table 5 shows a system which is corrected for spot aberrations  $< 1$  mm in scanning direction. Because the rema blades are essentially required to avoid the overscan in scanning direction, it is sufficient to achieve the required  
20 performance in scanning direction; here in y-direction.

In figure 9 the same elements as in figures 1 to 8 are designated with the same reference numbers. In figure 9.1 and 9.2 the spot-diagrams for a point in the centre of the field 100 and for an edge point 102 is depicted.

25

The optical data of the system according to figure 9 are shown in table 5.

The embodiment according to figure 9 is again a 1:1 imaging system and is derived from the embodiment according to figure 8.

30

**Table 5:**

System corrected for COMA, astigmatism and spherical aberration

first imaging mirror 5	Hyberbola	second imaging mirror 7	Ellipse
$\alpha_2$	8.9395	$\alpha_3$	6.4304
$\delta_2$	1.9988	$\delta_3$	20.5977
$\omega_2$	15.8802	$\omega_3$	33.4585
$d_2 = \text{YDE}$	283.1433	$d_3 = \text{YDE}$	587.5428
a2	5949.4780	a3	1371.5001
b	2942.2505	b	1329.5276
e	6637.2529	e	336.7028
R	-1455.0585	R	-1288.8396
$\text{eps} = e/a$	1.1156	$\text{eps} = e/a$	0.2455
$K = -\text{eps}^2$	-1.2446	$K = -\text{eps}^2$	-0.0603
ZDE	29.4941	ZDE	143.7641

The image plane 9 comprising the reticle is tilted with respect to the chief ray by 6°-angle of incidence. For a minimized spot aberration also the object plane 3 has to be tilted. In the example the optimized tilt angle of the object plane 3, where the field stop or rema has to be placed, is approximately 0.9768°.

Also shown in figures 8 and 9 are the complete first hyperbolic imaging 5 and the complete second elliptic imaging mirror 7 of the imaging system with the first axis of rotation 50 and the second axis of rotation 52. As is apparent from figure 9 the rays impinging the mirrors of the imaging system off-axis; this means that the used area of the two mirrors are situated off-axis with regard to the axis of rotation of the two mirrors. Also clearly shown the angle  $\gamma$  between the two axis of rotation.

In figure 10 an even better performing imaging system than the system according to figure 8 is shown. The same reference numbers as for the system according to figure 9 are used. The system according to figure 10 is derived from a more balanced optimization. This time the magnification is  
5  $\beta \approx -0,85$ .

The limiting aberrations in the imaging system according to the invention is COMA and astigmatism.

10 For field imaging a mirror 5 near to conjugate pupil plane 42 is used. This mirror 5 is aimed not to affect pupil imaging. If one looks at the aberrations in a plane which contains the focus, for field points different from the focus there are field aberrations. That is the case of the hyperbola, which is actually limited by astigmatism. For a given field of view size the smaller the  
15 tilt angle of the hyperbola, the smaller the angle of the field objects and, therefore, the smaller the astigmatism.

An elliptical mirror 7 is chosen for pupil imaging. The ellipse case is more complicated because the parameters are found to give stigmatic imaging at  
20 the centre of the exit pupil, not in the field plane 7. When used off axis for other conjugates different than the two geometrical foci, the ellipse introduces coma, and this is what can be seen in the field plane 7. Once more, the way of reducing this coma is minimising the tilt and balancing COMA between the first mirror 5 and the second mirror 7 of the imaging  
25 system.

The spot diagrams for the centre field point 100 and an edge field point 102 for a system according to figure 10 are depicted in figures 10.1 and 10.2. As is apparent from figure 10.2 the edge sharpness EDS for an edge field point  
30 is better than 1 mm in the scanning direction as well as in the direction perpendicular to the scanning direction. Said embodiment is a preferred

embodiment since the required imaging performance of the imaging system is also achieved in the direction perpendicular to the scanning direction; here in the x-direction.

- 5      The data of the system according to figure 10 are given in Code-V-format in table 6.

Table 6:

Code V-table of a imaging system with  $\beta = -0.85$ 

!	Radius	distance to next surface	Surface typ			
5	S0	0	0	DAR;	ADE	6,0;
	S	0	-369.481	REFL		
	S	0	-110.093			
	S	6964.67	0	REFL	!	first imaging mirror 5
	CON					
10	K	-205.127				
	DAR;			ADE	-19.23631;	
			YDE	149.7571;	ZDE	50.40653
	S	0	0			
				ADE	-36.0;	
15	S	0	500.9524			
	S	0	0			
				ADE	10.0;	
	S	-898.3867	0	REFL	!	Second imaging mirror 7
	CON					
20	K	-0.2302684				
	DAR;			ADE	5.464502;	
			YDE	164.4807;	ZDE	-0.638
	CIR	1000				
	S	0	-797			
25	S	0	0	REFL		
	BEN;			ADE	-6.0;	
	CIR	500				
	SI	0	0	!Reticle		
30	DAR			ADE	6.0	



In figure 11 a EUV-illumination system with a ripple-plate 200 as field-forming component and an multi-mirror-system comprising an imaging system 1 according to the invention is shown. The system comprising a light source 12, a collector unit 14, a ripple-plate 200 as a field-forming component for the arc-shaped field and a field mirror (202) is known from Henry N. Chapman et al. a.a.O; the content of said article is incorporated herein by reference.

The imaging system shown in figure 11 is identical to the imaging systems according to figures 1 to 10. The same elements as in figures 1 to 10 are designated with the same reference numbers.

Other setups then those of figure 11 are possible, in which the light is not collimated before the ripple plate 200, but converging to a focal point. In this case the grooves of the ripple plate are not parallel, but conically, i.e. the prolongation of the grooves meet in one point corresponding to the focal point of the incident wave.

The shape of the ripple plate 200 can be derived theoretically, but has to be optimized. The pupil formation with the ripple design leads to an elliptical illumination of the exit pupil after the illumination system corresponding to the entrance pupil of the lens system. Therefore an aperture stop is required in a conjugate pupil plane. This aperture stop will also lead to light loss. The ellipticity of the pupil increases with the lateral coordinate, along the arc-field perpendicular to scanning direction. The light loss has to be compensated for by shaping the ripple plate aspherically.

Next, two examples of hyperbola - ellipsoid-combinations for the imaging mirrors 5, 7 are shown with  $\beta = -1.5$ . The first order system is analytically derived, as described before. The second system is optimized for a better

performance in scanning direction. The parameters are given in tables 7 to 9:

**Table 7:** First-order parameters for  $\beta_{\text{rema}} = -1.5$  - system.

first imaging mirror 5	Hyberboloid	second imaging mirror 7	Ellipsoid
	e 23	650.00	
$f_2$	495.9484	$f_3$	721.5351
pupil imaging			
SE2	-271.5174	SE3	-1250.0000
SE2'	-600.0000	SE3'	1706.6772
$\beta_2$	2.2098	$\beta_3$	-1.3653
field imaging			
SR2	-482.9048	SR3	-19011.2108
SR2'	-18361.2108	SR3'	750.0000
$\beta_2$	38.0224	$\beta_3$	-0.0395

If one corrects the coma of the system of table 7 according to analytic solution of ellipsoid and hyperboloid, as shown before, a system as shown in table 8 and figure 12 results. The spot aberrations are shown in figure 12.1 and figure 12.2 for a centre field point 100 and an edge field point 102.

**Table 8:** COMA corrected system

first imaging mirror 5		second imaging mirror 7	
$\alpha_2$	8.4600	$\alpha_3$	6.5000
$\delta_2$	0.4278	$\delta_3$	29.9146
$\omega_2$	16.4922	$\omega_3$	42.9146
$d_2 = \text{YDE}$	137.04894	$d_3 = \text{YDE}$	851.1340
$\alpha_2$	8939.1530	$\alpha_3$	1478.3386
b	2945.3024	b	1441.2091
e	9411.8682	e	281.9172
R	-970.4282	R	-1424.5774
$\text{eps} = e/a$	1.0529	$\text{eps} = e/a$	0.1907
$K = -\text{eps}^2$	-1.1086	$K = -\text{eps}^2$	-0.0364
$\text{ZDE} = z-a$	9.9779	$\text{ZDE} = a-z$	280.9593

The embodiment according to figure 13 and table 9 is optimized to achieve spot aberration less than 1 mm in scanning direction:

**Table 9:** Optimized design

first imaging mirror 5		second imaging mirror 7	
$\alpha_2$	8.0302	$\alpha_3$	6.2127
$\delta_2$	0.1706	$\delta_3$	30.3800
$\omega_2$	16.2310	$\omega_3$	42.8054
$d = \text{YDE}$	139.9744	$d = \text{YDE}$	848.9438
R	-967.1380	R	-1415.0130
$K = -\text{eps}^2$	-1.1933	$K = -\text{eps}^2$	-0.04913
$\text{ZDE} = z-a$	11.3839	$\text{ZDE} = a-z$	284.2995

In the following section an illumination system with an arbitrary field, e.g. a rectangular field in the object plane 3 is discussed. The schematic set-up for such systems are shown in figures 14 and 15. In both examples the imaging system images a rectangular field 300 into an arc-shaped field 302.

5      Consequently arc-shaped rema blades or field stop 304 have to be applied to compensate for the deformation induced by the imaging with grazing incidence field mirror 306 as shown in figure 16. Furthermore in figure 16 the clipping 308 in the image or rema-plane 9 is shown.

10      The system according to figures 14 and 15 comprises: an object plane 3 at least, a first imaging normal incidence mirror 5 and at least one grazing incidence mirror 306 for forming the arc-shaped field in the image plane 9.

15      A realisation of a system with one grazing incidence mirror 306 is given in figure 17. To achieve the desired orientation for the ring field, a field lens with negative optical power is required. The radius of the arc-shaped field is approximately 138 mm, however, by the angle of incidence and the optical power of the first imaging mirror 5 almost any desired field radius is achievable. Table 10 gives the data for such a system, where for the  
20      magnification  $\beta_{\text{image}} = -1.2$  was chosen.

**Table 10:**

first imaging mirror 5	ellipsoid	second imaging mirror 7	hyperboloid
$\alpha_1$	12.0	$\alpha_2$	78.0
	e 23	500.00	
$f_1$	382.1450	$f_2$	-868.3020
field imaging			
SE1	-609.7360	SE2	523.8000
SE1'	1023.8000	SE2'	1320.2146
$\beta_1$	-1.6791	$\beta_2$	2.5205
pupil imaging			
SR1	-810.6258	SR2	222.9651
SR1'	722.9651	SR2'	300.0000
$\beta_1$	-0.8919	$\beta_2$	1.3455
surface parameters			
$\delta_1$	27.9820	$\delta_2$	14.2042
$\omega_1$	51.9820	$\omega_2$	38.2042
e	264.2854	e	434.1220
d	480.3602	d	323.9526
b	772.8280	b	172.8956
a	816.7680	a	398.2073
p = R	-731.2519	p = R	75.0687
eps	0.3236	eps	1.0902
K	-0.1047	K	-1.1885
z	639.8277	z	845.7300

The arcuate field is demonstrated in figure 17.1. A rectangular aperture was ray-traced through the system until the reticle plane. Here the arc-shaped field arises due to the grazing incidence reflection at the grazing incidence

mirror 306. However, the spot diameter is in this un-optimized example about 10 mm. Due to the imaging with one normal incidence and one grazing incidence mirror, a large amount of coma is introduced, which can not be reduced effectively.

5

A reduction of coma is possible by insertion of a second normal incidence mirror 7. An example is shown in figure 18, the corresponding data are given in table 11 (with  $\beta_{\text{image}} \approx -1.272$ ). The illumination at reticle field is

10

shown in figure 18.1. The system has capability to be optimized further to similar performance as system examples given before by similar straight forward optimization, which means proper selection of reflection and folding angles.

**Table 11:**

first imaging mirror 5	ellipsoid	second imaging mirror 7	hyperboloid	grazing incidence mirror	hyperboloid
$\alpha_0$	8.0	$\alpha_1$	11.0	$\alpha_2$	12.0
	e 01	450.0000	e12	500.000	
$f_0$	668.2746	$f_1$	1055.6841	$f_2$	-668.302
pupil imaging					
SE0	-700.0360	SE1	3455.9	SE2	523.8
SE0'	35000.0	SE1'	1023.8	SE2'	1320.2148
$\beta_0$	-50.0	$\beta_1$	0.0298	$\beta_2$	2.5205
field imaging					
SR0	-914.8405	SR1	2296.8290	SR2	222.9651
SR0'	2746.8290	SR1'	722.9651	SR2'	300.0
$\beta_0$	-3.0025	$\beta_1$	0.3148	$\beta_2$	1.3455
$\delta_0$	7.6903	$\delta_1$	21.3810193242	$\delta_2$	14.2042
$\omega_0$	23.6903	$\omega_1$	0.6189808758	$\omega_2$	38.2042
b	1569.789	b	5838.1891984484	b	172.8958
a	1830.8348	a	18763.1000000000	a	398.2073
p = R	-1345.9839	p = R	-2033.3024973819	p = R	-75.0687
eps	0.5148	eps	1.0589128053	eps	1.0902
K	-0.2448	K	-1.1212963293	K	-1.1885
e	942.1881	e	17750.6812469375	e	434.122
d	367.5783	d	373.24505478583	d	323.9526
z	1779.9358	z	-16797.3228034857	z	845.73

## Reference numbers:

	1:	imaging system
	3:	object plane = field plane
5	3':	virtual image of the field plane
	5:	first imaging mirror
	9:	image plane
	10:	exit pupil
	10':	virtual image of the exit pupil
10	12:	light source
	14:	collector
	16:	means for enhancing the entendu
	18:	first field forming mirrors
	20:	second field forming mirrors
15	30:	first mirror with raster elements
	32:	second mirror with raster elements
	40:	first plane conjugate to the exit pupil
	42:	second plane conjugate to the exit pupil
	50:	axis of rotation of the first imaging mirror
20	52:	<del>axis of rotation of the second imaging mirror</del>
	54:	centre of the first imaging mirror
	56:	vertex of the first imaging mirror
	58:	centre of the second imaging mirror
	60:	vertex of the second imaging mirror
25	62:	chief ray
	70:	lower COMA ray
	100:	field point in the centre of the arc shaped field
	102:	field point at the edge of the arc shaped field
	200:	ripple plate
30	300:	rectangular field
	302:	arc shaped field



- 304: field stop
- 306: grazing incidence mirror
- 308: clipping
- ePO: distance between first mirror and first plane conjugate to the exit  
5 plane
- e01: distance between first and second field forming mirror
- EDS: edge sharpness
- SE1': distance between second field forming mirror and second plane  
conjugate to the exit pupil
- 10 SR1': distance between second field forming mirror and object plane
- SE2: distance between second plane conjugate to the exit pupil and first  
imaging mirror
- x: direction perpendicular to the scanning direction
- y: direction in scanning direction
- 15  $\gamma$ : angle between the axis of rotation 50, 52
- $f_i$ : focal length of optical component i
- $\alpha_i$ : angle of incidence of chief ray with respect of surface normal of  
mirror i
- $\beta_{\text{pupil}}$ : magnification for pupil imaging between conjugate pupil planes
- 20  $\beta_{\text{field}}$ : magnification for field imaging between conjugate field plane and  
reticle plane
- $\beta_i$ : magnification for the intermediate imaging at a single optical element,  
either for pupil or for field imaging (depending on context)
- R: field radius
- 25 S: working distances
- SEi: working distance with respect to entrance pupil imaging between  
mirror i on object side
- SEi': working distance with respect to entrance pupil imaging between  
mirror i on image side
- 30 SRI: working distance with respect to field imaging between mirror i on  
object side

- 5       $SRI'$ : working distance with respect to field imaging between mirror  $i$  on  
          image side  
           $e_{ij}$ : distance between optical element  $i$  and  $j$   
           $\omega_i$ : angle between incident chief ray and rotation axis of optical element  $i$   
           $\delta_i$ : angle between reflected chief ray and rotation axis of optical element  $i$   
           $a, b, e$ ,  
           $\varepsilon, p, K$ : conic section parameters for individual mirror  
           $d_i$ : transversal co-ordinate of intersection point of chief ray with mirror  $i$   
          with respect to rotation axis  
 10       $z_i$ : longitudinal co-ordinate of intersection point of chief ray with mirror  $i$   
          with respect to centre of conic section  
           $\beta_{c\pm}$ : magnification for upper or lower coma or rim rays  
          YDE,  
          ZDE: decenter vector components as usual in optical design programs  
 15      (e.g. CODE V).

## Patent Claims

1. Multi-mirror-system for an illumination system, especially for lithography with wavelengths  $\leq 193$  nm  
5 comprising an imaging system, wherein said imaging system comprises least a first mirror (5) and a second mirror (7)
  - 1.1 an object plane (3)
  - 1.2 an image plane (9), wherein the imaging system forms an image of the object
  - 10 1.3 an arc-shaped field in said image plane (9), whereby the radial direction of in the middle the arc-shaped field defines a scanning direction
  - 1.4 the multi-mirror-system is characterized in that
  - 1.5 at least said first mirror (5) and said second mirror (7) of said imaging  
15 system are arranged in the optical path of the imaging system in such a position and having such a shape, that the edge sharpness of the arc-shaped field in the image plane is smaller than 5 mm, preferably 2 mm, most preferably 1 mm in scanning direction.
- 20 2. Multi-mirror-system according to claim 1, characterized in that at least said first mirror (5) and said second mirror (7) of said imaging system are arranged in the optical path of the imaging system in such a position and having such a shape, that the edge sharpness of the  
25 arc-shaped field in the image plane is smaller than 5 mm, preferably 2 mm, most preferably 1 mm in the direction perpendicular to the scanning direction.
3. Multi-mirror-system according to claim 1 or 2, characterized in that the object in the object plane (3) is an arc-shaped field.

4. Multi-mirror-system according to one of the claims 1 to 3,  
characterized in that the rays travelling from the object plane (3) to  
the image plane (9) in the imaging system are impinging the first (5)  
and the second mirror (7) defining a first and a second used area on  
the mirrors, whereby the rays are impinging the first (5) and the  
second mirror (7) in the used area with an incidence angle relative to  
the surface normal of the mirror  $\leq 30^\circ$  or  $\geq 60^\circ$ , especially  $\leq 20^\circ$  or  $\geq 70^\circ$ .
5. Multi-mirror-system according to one of the claims 1 to 4,  
characterized in that,  
the magnification ratio of the field imaged by the imaging system is  
unequal to 1.
6. Multi-mirror-system according to one of the claims 1 to 5,  
characterized in that,  
the imaging system is a non centred system.
7. Multi-mirror-system according to one of the claims 1 to 6,  
characterized in that,  
a field stop is located in or close to the object plane (3).
8. Multi-mirror-system according to one of the claims 1 to 7,  
characterized in that,  
the imaging system comprises an exit pupil (10) and an aperture stop  
is located on or close to the plane (42) conjugate to the exit pupil  
(10).
9. Multi-mirror-system according to one of the claims 1 to 8,  
characterized in that,

the imaging system comprises an exit pupil (10) and said first mirror is positioned close to the plane (42) conjugate to the exit pupil (10).

10. Multi-mirror-system according to one of the claims 1 to 9,  
characterized in that,  
said first and/or the second mirror is an aspheric mirror.

11. Multi-mirror-system according to one of the claims 1 to 10,  
characterized in that,  
the first mirror (5) is a concave mirror having a nearly hyperbolic form or a nearly elliptic form and is defining a first axis of rotation (50).

12. Multi-mirror-system according to one of the claims 1 to 11,  
characterized in that,  
the second mirror (7) is a concave mirror having a nearly hyperbolic form or a nearly elliptic form and is defining a second axis of rotation (52).

13. Multi-mirror-system according to one of the claims 11 to 12,  
characterized in that,  
the first (5) and the second mirror (7) is comprising a used area in which the rays travelling through the imaging system are impinging the first and the second mirror; the used area is arranged off-axis in respect to the first and second axis of rotation.

14. Multi-mirror-system according to claim 11-13,  
characterized in that,  
the first axis of rotation (50) and the second axis of rotation (52) subtend an angle  $\gamma$  and  
the first mirror and the second mirror are defining a first magnification for the chief ray travelling through the centre of the field and the

centre of the exit pupil, a second magnification for the upper COMA ray travelling through the centre of the field and the upper edge of the exit pupil and a third magnification for the lower COMA ray travelling through the centre of the field and the lower edge of the exit pupil, whereby the angle  $\gamma$  between the first (50) and the second (52) axis of rotation is chosen such that the first, the second and the third magnification is nearly identical.

5

15. Multi-mirror-system for an illumination system, especially for lithography with wavelengths  $\leq 193$  nm comprising an imaging system, wherein said imaging system comprises

10

15.1. an object plane (3)

15.2. an image plane (9), wherein the imaging system forms an image of the object

15

15.3. an arc-shaped field in said image plane (9)

15.4. the multi-mirror-system is characterized in that

15.5. said imaging system comprises at least a normal incidence mirror (5, 7) and a field forming optical component.

20

16. Multi-mirror-system according to claim 15, characterized in that the object in the object plane is an arbitrary field.

25

17. Multi-mirror-system according to one of the claim 16, characterized in that, the field in the object plane is a rectangular field and the rectangular field is formed into an arc-shaped field in the image plane by the field forming optical component.

30

18. Multi-mirror-system according to claims 15 to 17,  
characterized in that,  
said field forming component comprises at least one grazing-  
incidence-mirror.
- 5
19. Multi-mirror-system according to claim 18,  
characterized in that,  
said grazing incidence mirror has negative optical power.
- 10
20. Multi-mirror-system according to claim 18,  
characterized in that,  
said field forming component comprises a first grazing incidence  
mirror with positive optical power and a second grazing incidence  
mirror for rotating the field.
- 15
21. Multi-mirror-system according to one of the claims 15 to 19,  
characterized in that,  
said imaging system comprises two normal incidence mirrors (5, 7)  
and one grazing incidence mirror (306) as field forming component.
- 20
22. Multi-mirror-system according to one of the claim 15 to 21,  
characterized in that,  
the multi-mirror-system comprises a field stop located in the object  
plane.
- 25
23. Multi-mirror-system according to one of the claims 15 to 22,  
characterized in that,  
the magnification ratio of the field imaged by the imaging system is  
unequal to 1.
- 30
24. Multi-mirror-system according to one of the claims 15 to 23,

characterized in that,  
said at least normal incidence mirror(s) and/or said first grazing  
incidence mirror and/or said second grazing incidence mirror is an  
(are) aspheric mirror(s).

5

25. Multi-mirror-system according to one of the claims 15 to 24,  
characterized in that,  
said field forming component is positioned close to the image plane.

10

26. Multi-mirror-system according to one of the claims 15 to 25,  
characterized in that,  
said at least normal incidence mirror(s) and/or the first grazing  
incidence mirror and/or the second grazing incidence mirror is (are)  
comprising a used area in which the rays travelling through the  
imaging system is impinging the at least normal incidence mirror(s)  
and/or the first grazing incidence mirror and/or the second grazing  
incidence mirror and said used area is arranged off-axis with regard  
to the first axis.

15

20

27. Illumination system, especially for lithography with wavelengths  $\leq$   
193 nm  
comprising

27.1 a light source

25

27.2 a multi-mirror system comprising an imaging system, whereby the  
imaging system comprises an object plane

27.3 an optical component for forming an arc-shaped field in the object  
plane of the multi-mirror-system  
characterized in that



27.4 the multi-mirror-system is a system according to one of the claims 1 to 17 for imaging the field in the object plane into the image plane of the imaging system.

5 28. Multi-mirror-system according to claim 27,  
characterized in that,  
the illumination system comprises at least one mirror or one lens  
which is or which are comprising raster elements for forming  
secondary light sources.

10 29. Illumination system, especially for lithography with wave lengths  $\leq$   
193 nm  
comprising

29.1 a light source

15 29.2 a multi-mirror-system comprising an imaging system, whereby the  
imaging system comprises an object plane

29.3 an arbitrary field in said object plane

29.4 at least one mirror or lens device comprising at least one mirror or  
one lens, which is or are comprising raster elements for forming  
secondary light sources

20 characterized in that

29.5 the illumination system comprises a multi-mirror-system according to  
one of the claims 17 to 25.

25 30. EUV-projection exposure unit for microlithography comprising

30.1 an illumination system according to at least one of the claims 27 to  
29 with an exit pupil

30.2 a mask on a carrier system, said mask being positioned in the image  
plane of the imaging system

30 30.3 a projection objective with an entrance pupil, said entrance pupil  
being in the same plane as the exit pupil of the illumination system

30.4 a light sensitive object on a carrier system.

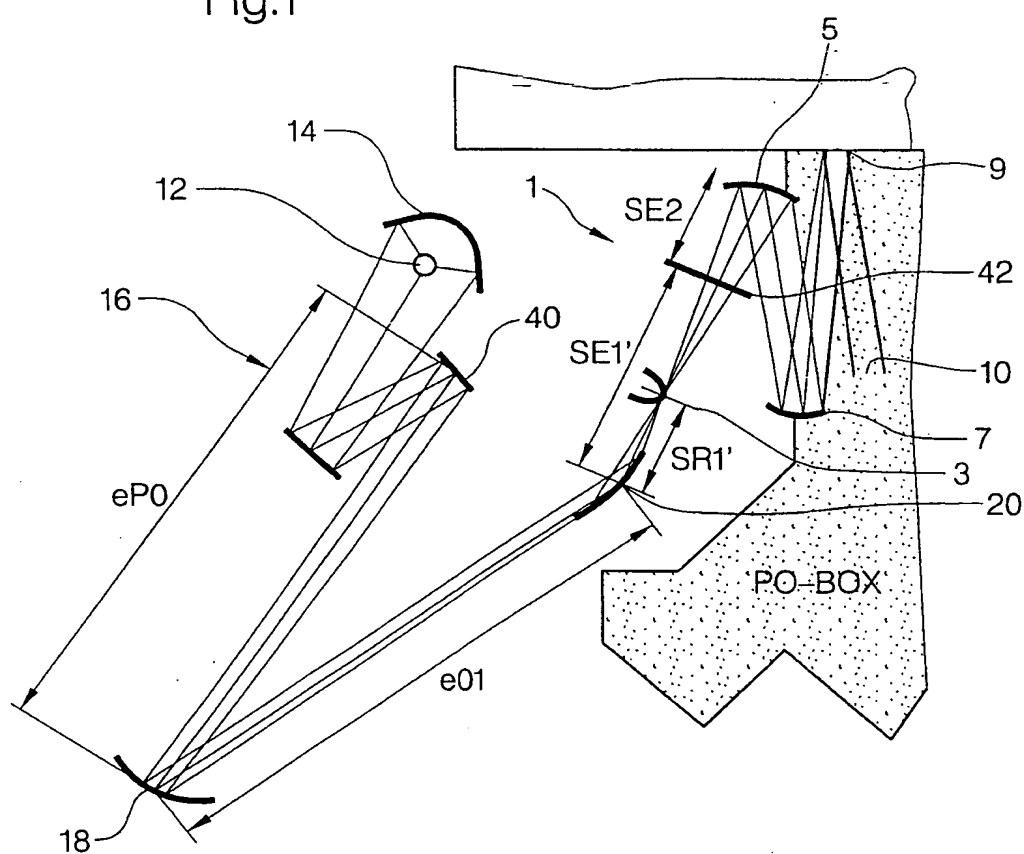
31. EUV-projection exposure unit according to claim 30, designed as a scanning system.

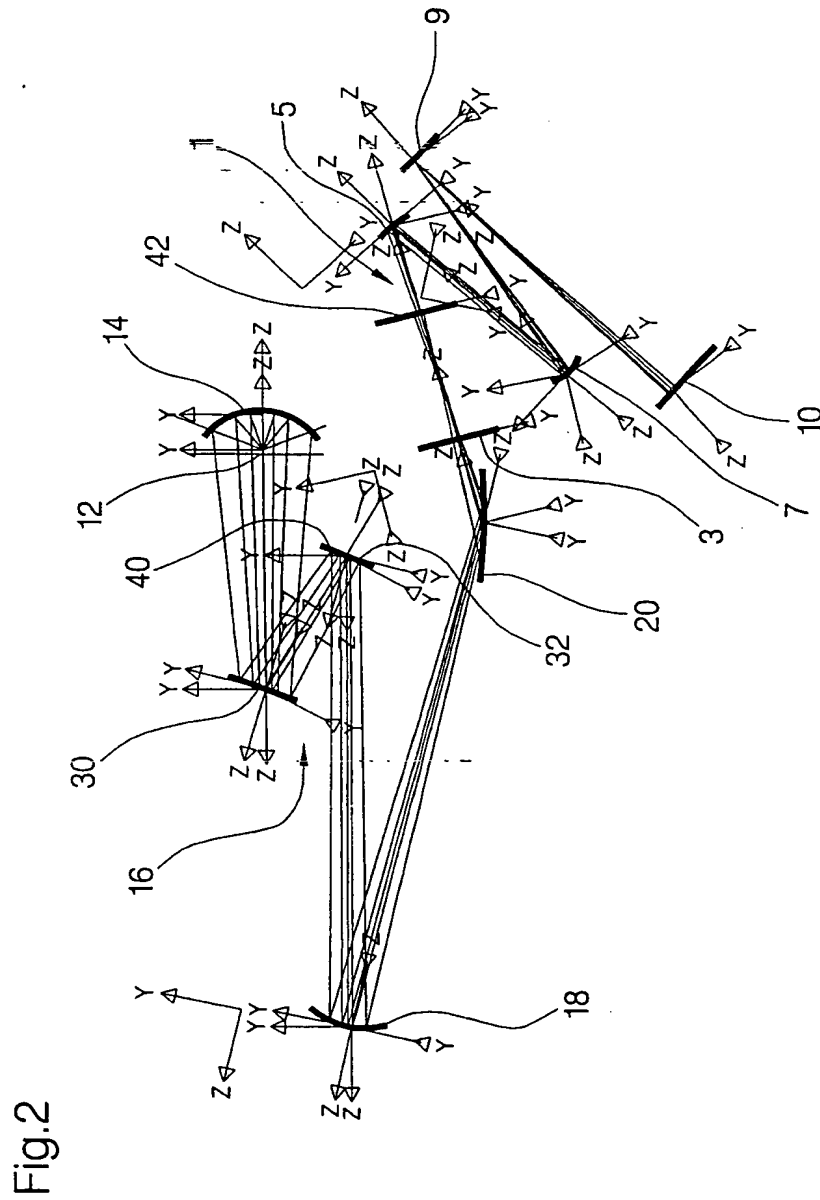
5

32. Process for producing microelectronic devices, especially semiconductor chips with a EUV-projection exposure unit according to claims 30 to 31.

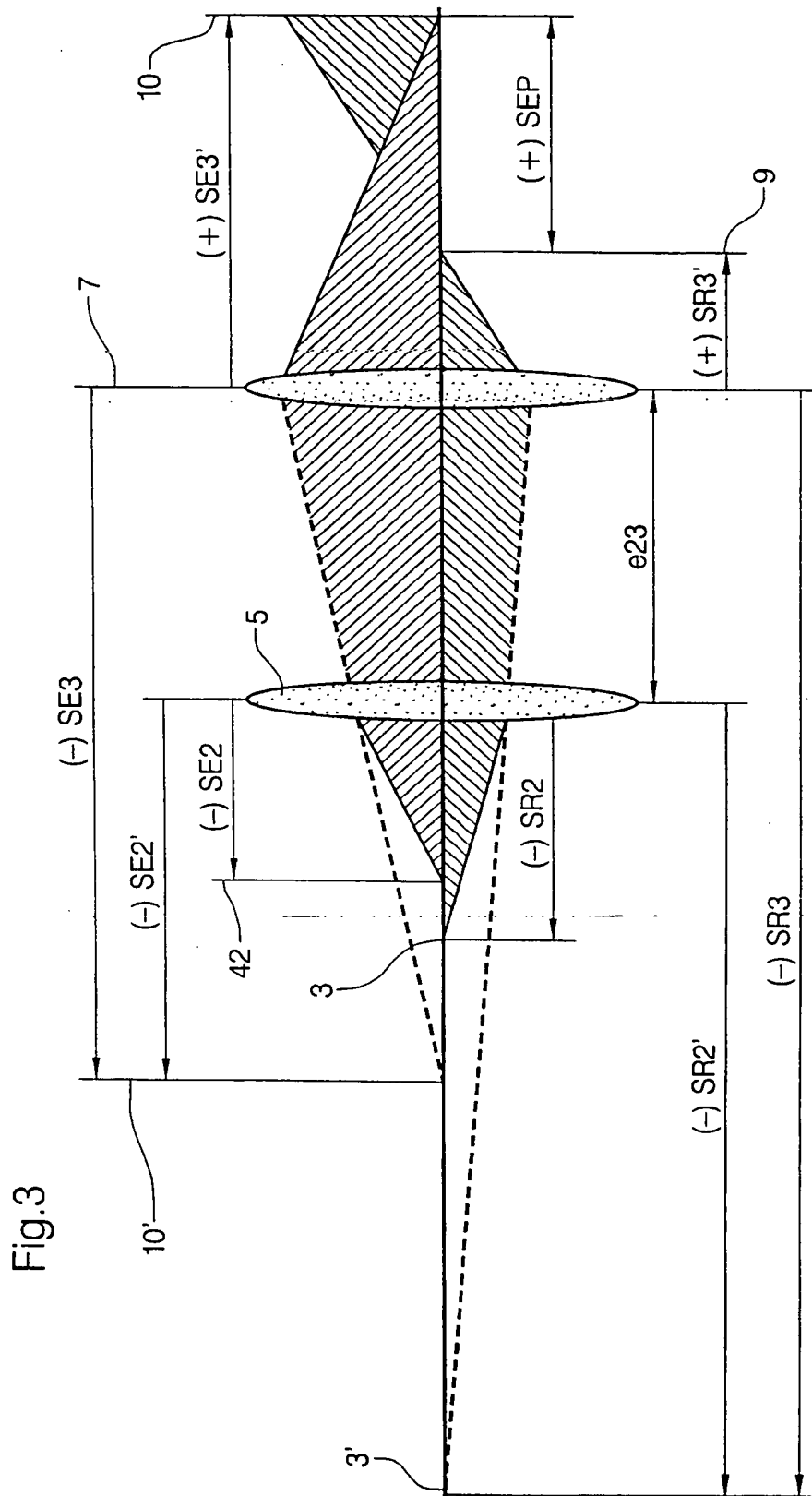
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Fig.1





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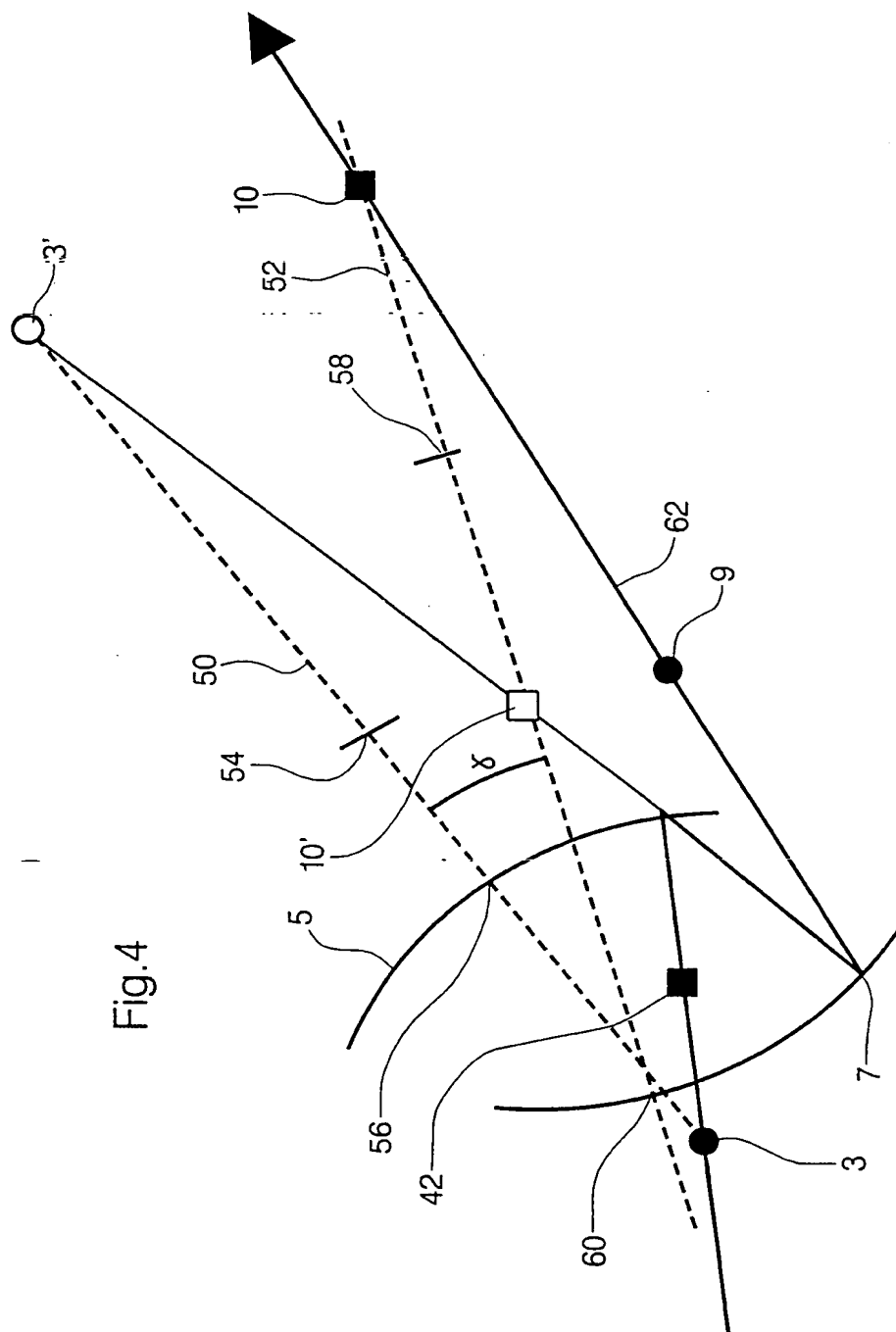


Fig.4

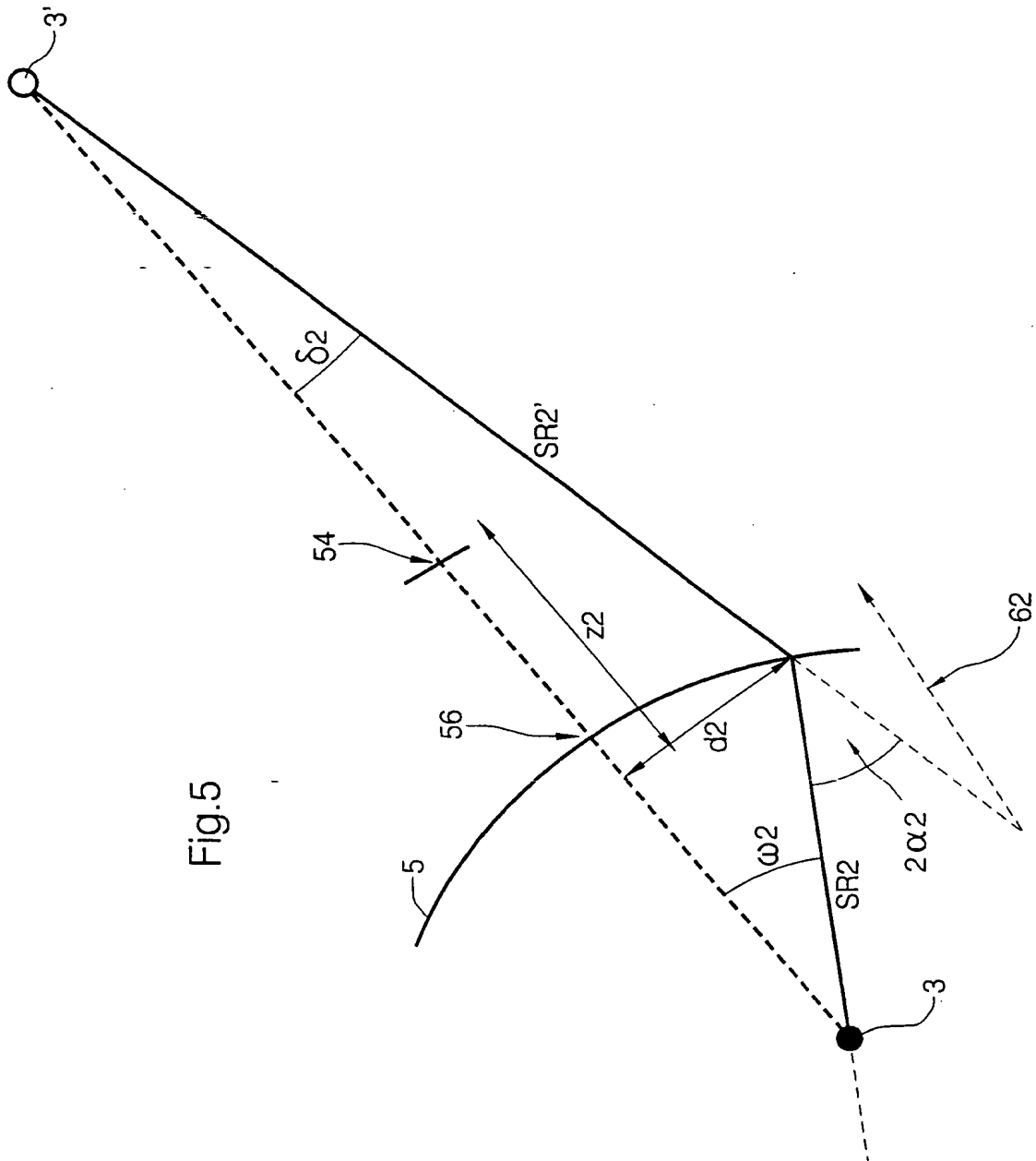
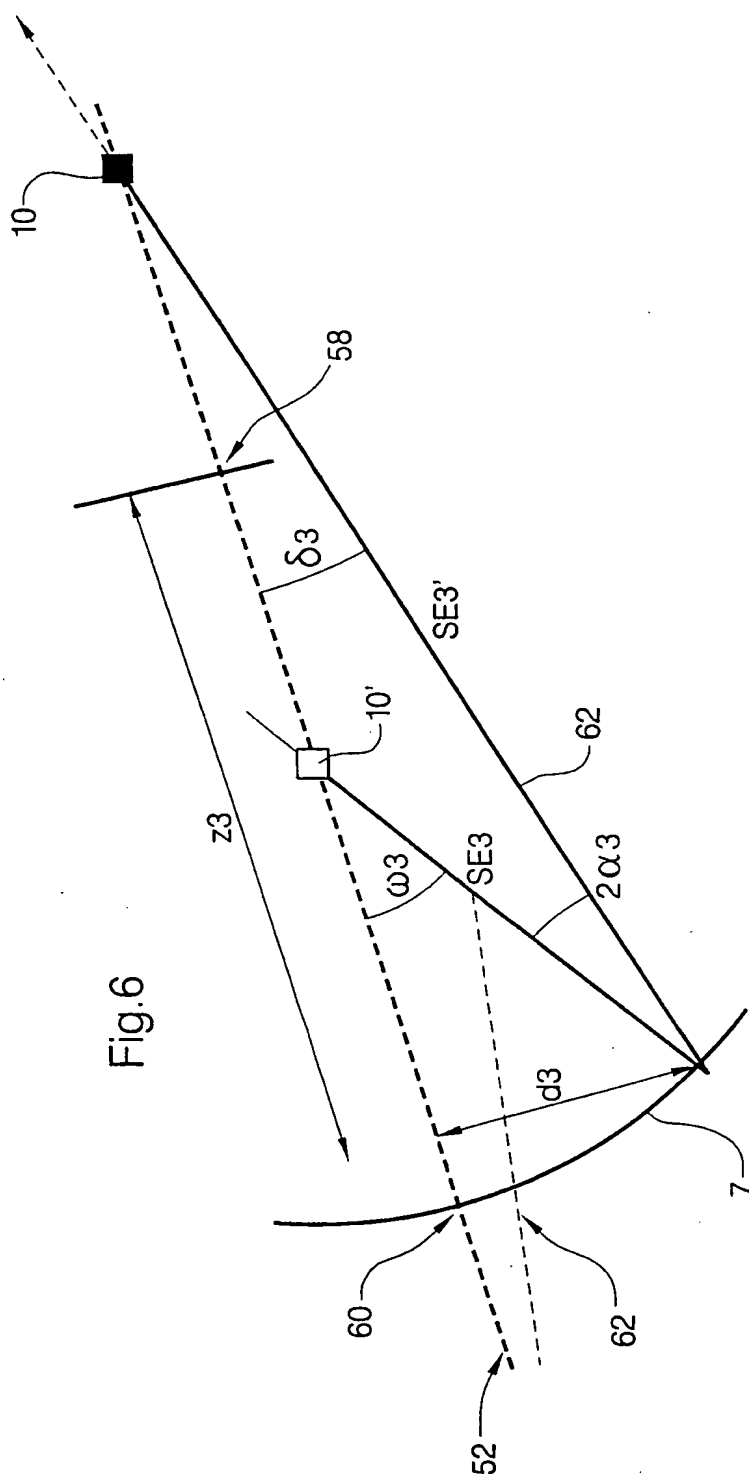


Fig.5





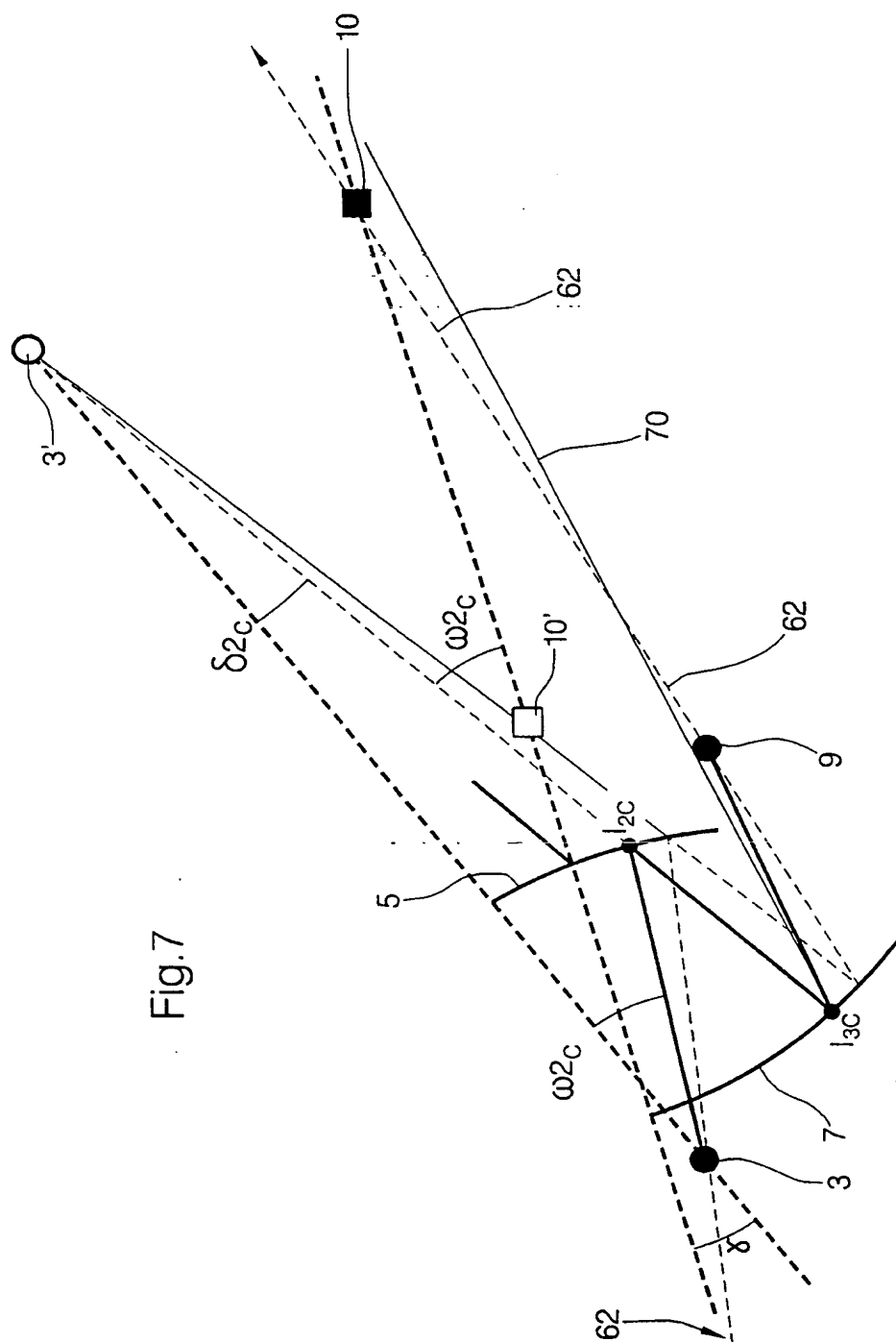
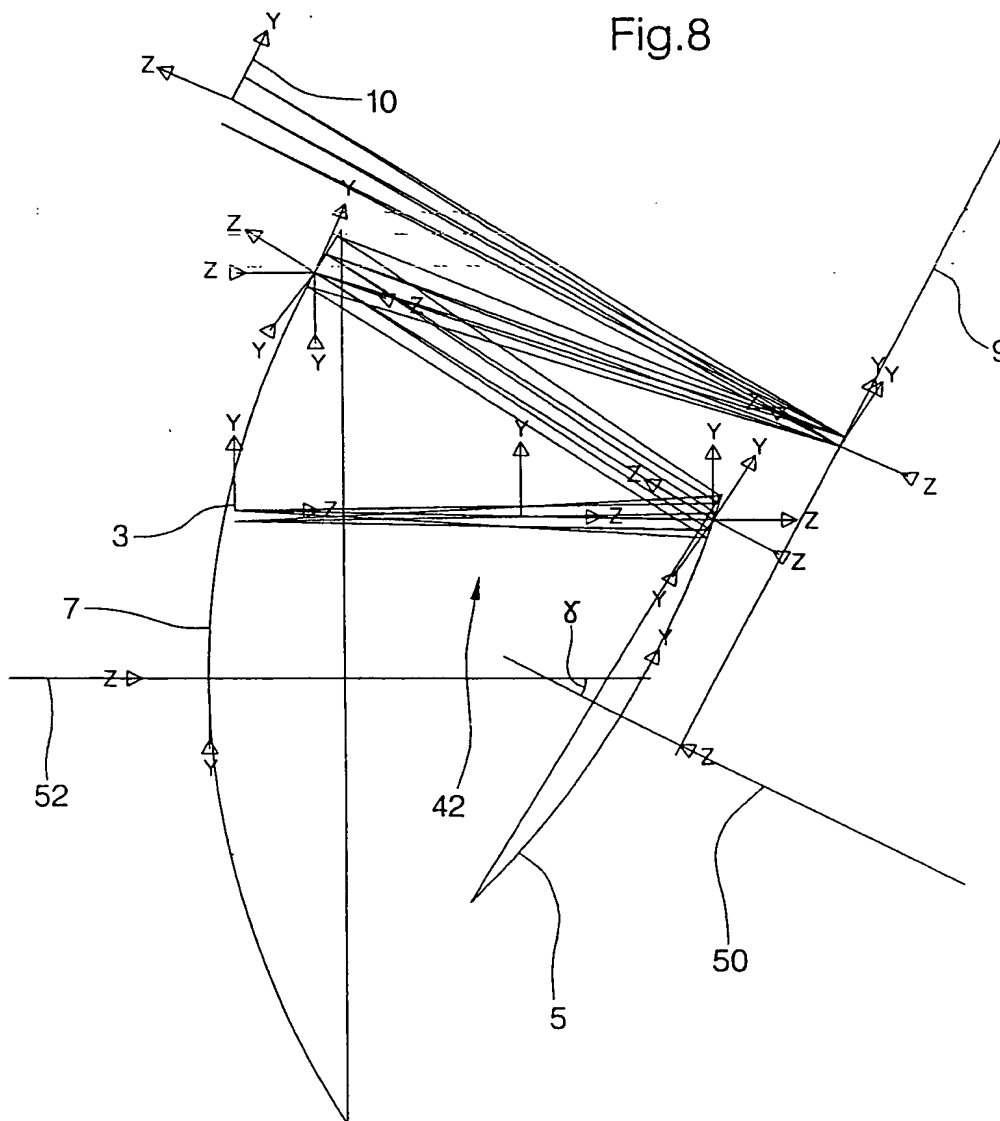
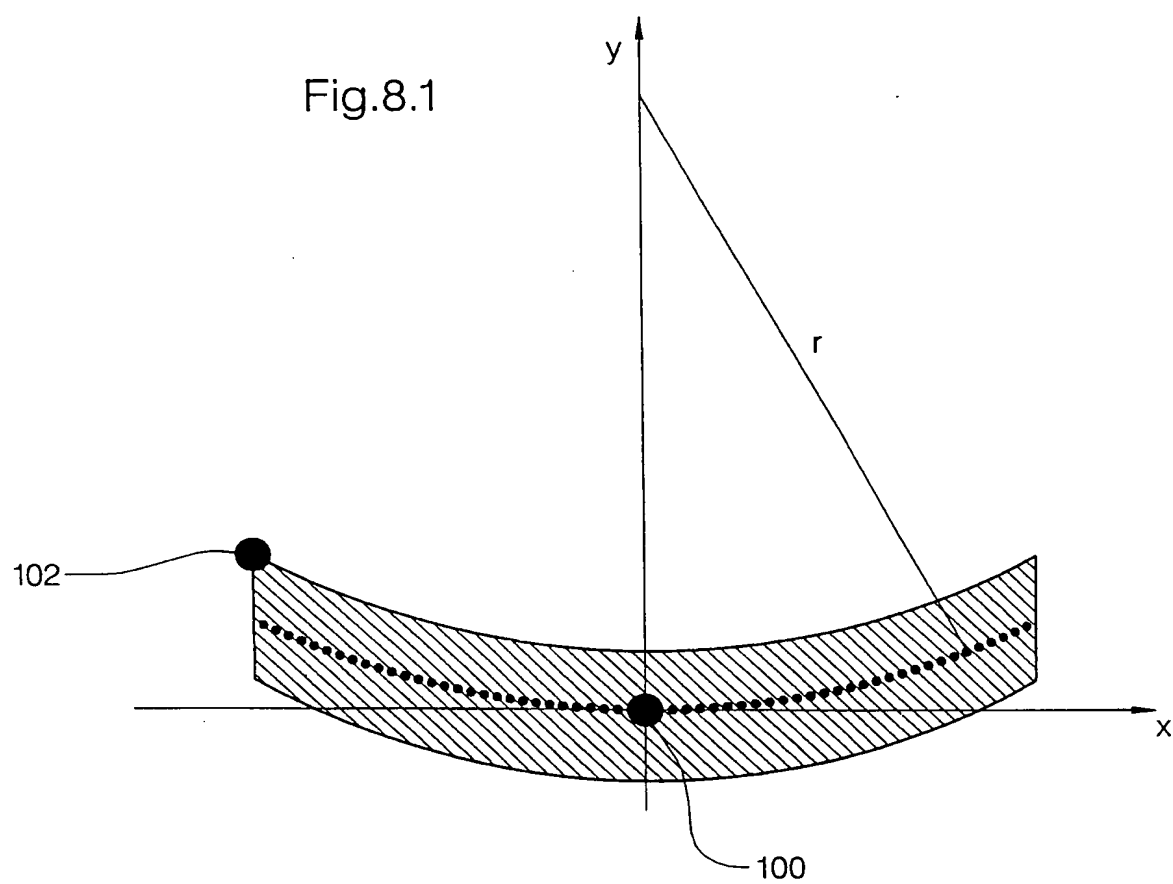


Fig.8



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Fig.8.3

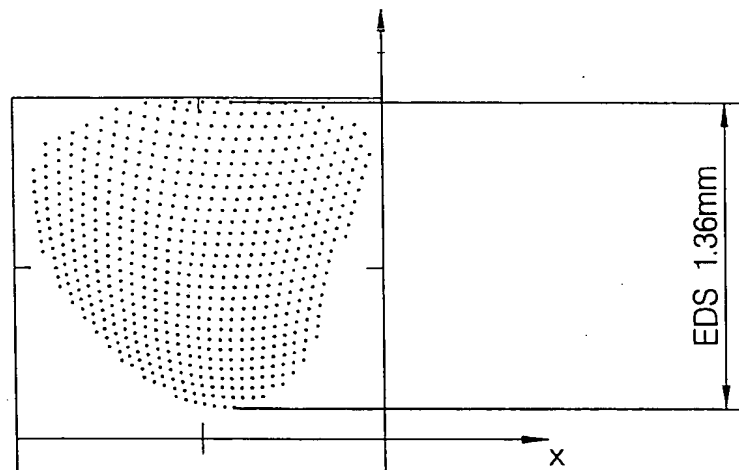


Fig.8.2

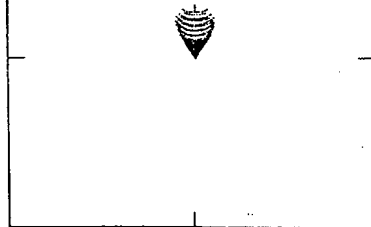
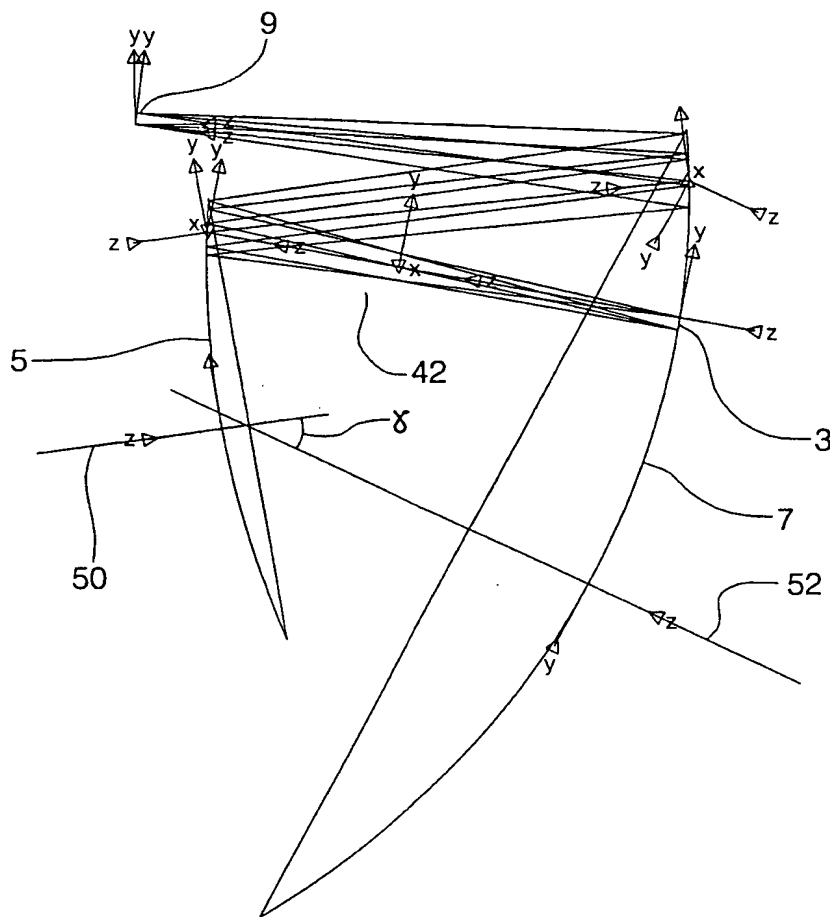


Fig.9



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Fig.9.2

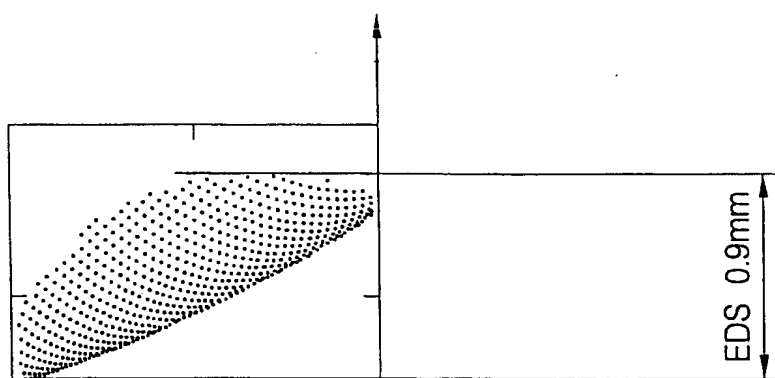


Fig.9.1

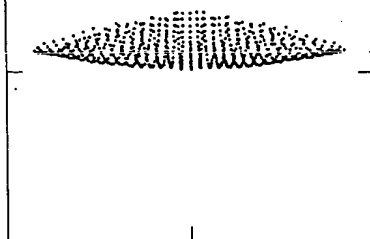
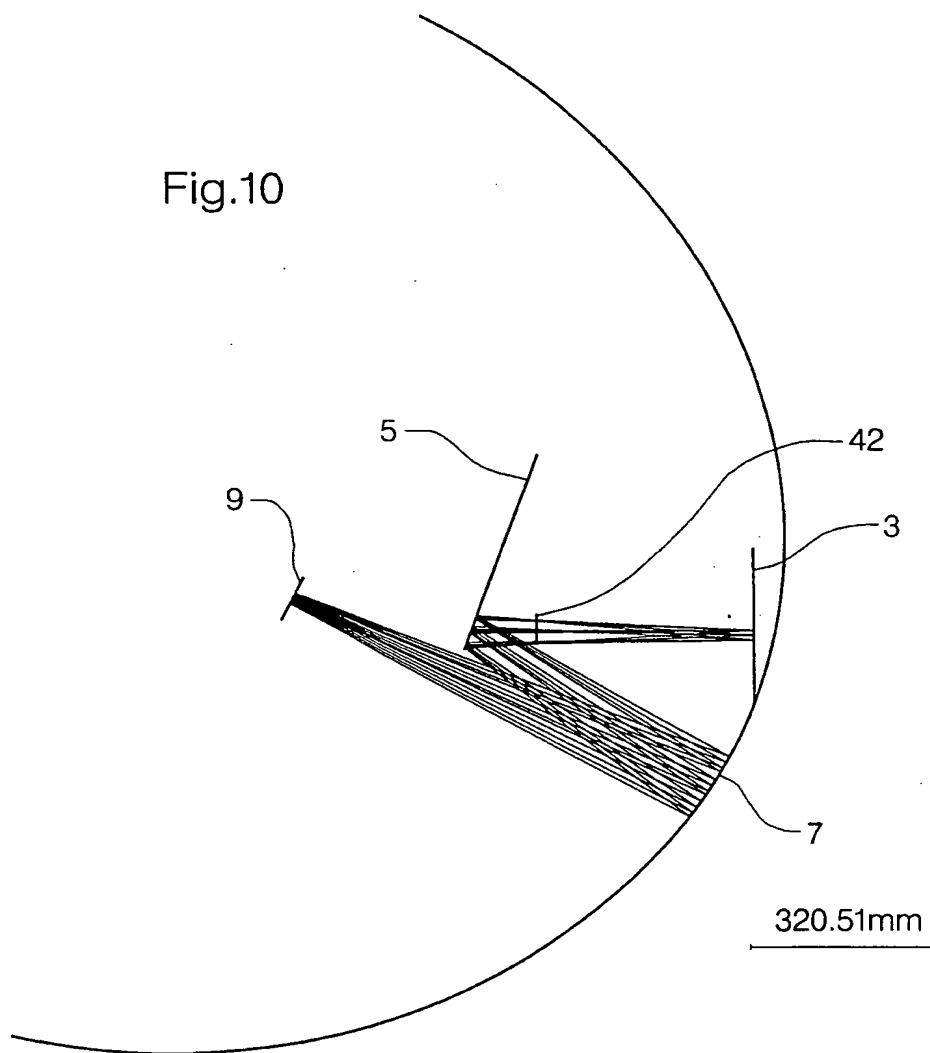


Fig.10

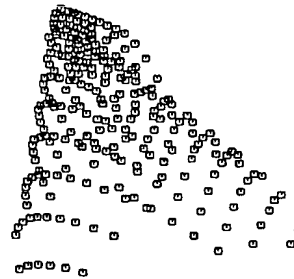


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FIELD  
POSITION

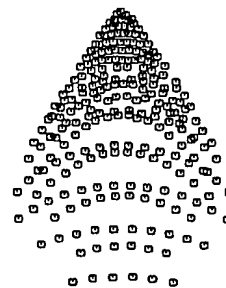
1.00, 1.00  
7.404, 1.995 DG

Fig.10.2



0.00, 0.00  
0.000, 0.000 DG

Fig.10.1



.235mm

DEFOCUSING

0.00000

SUBSTITUTE SHEET (RULE 26)



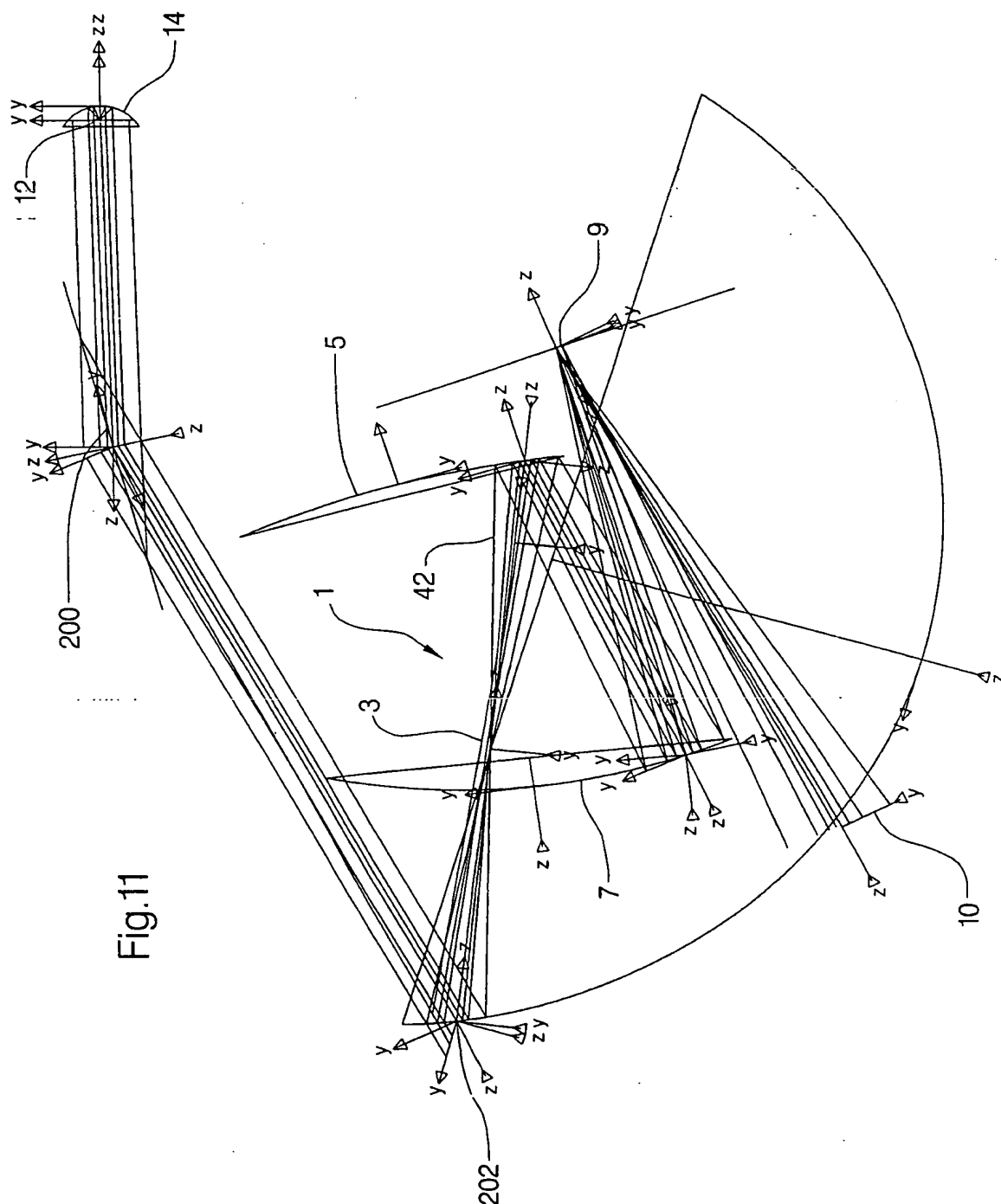


Fig.11

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Fig.12

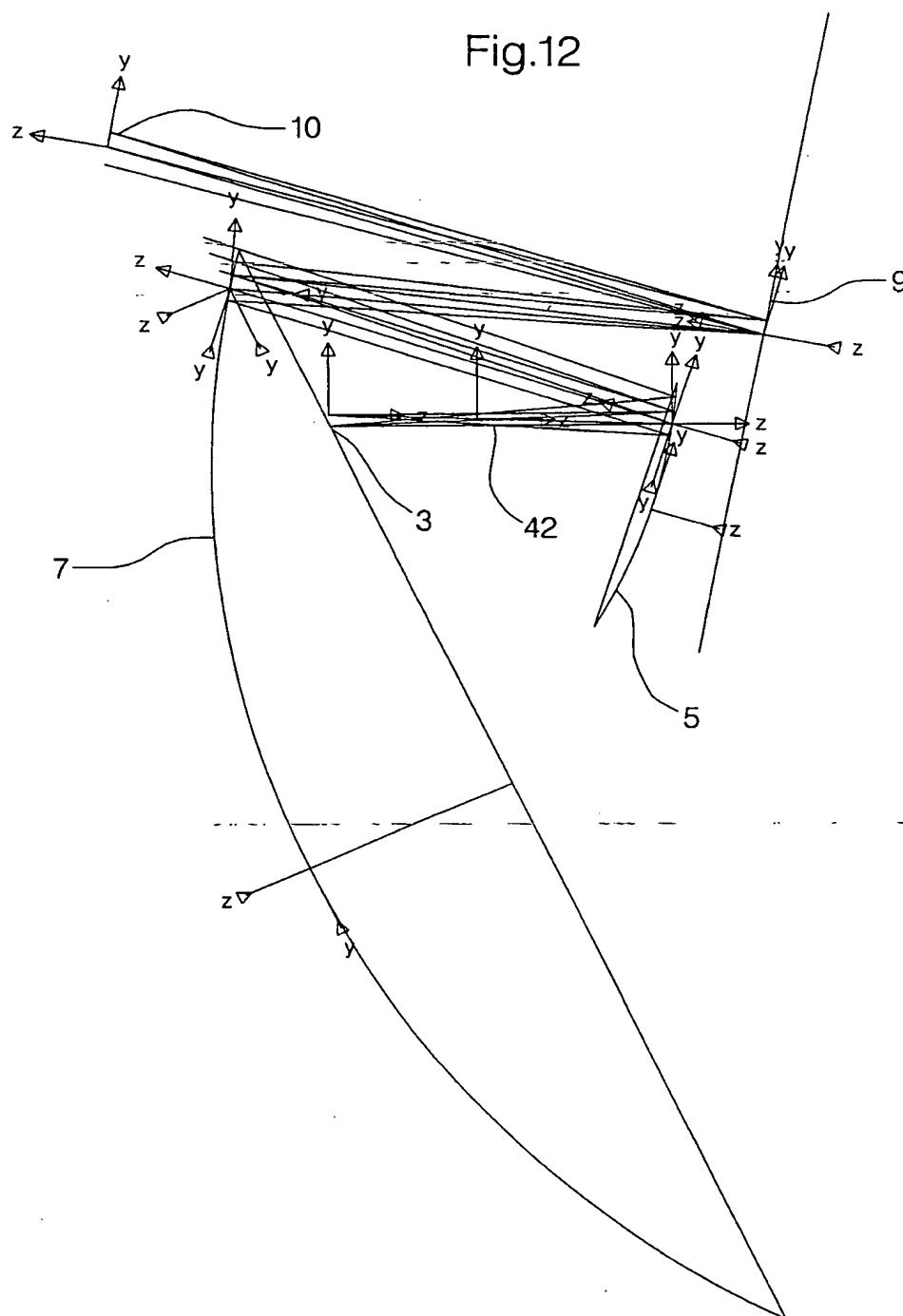


Fig.12.2

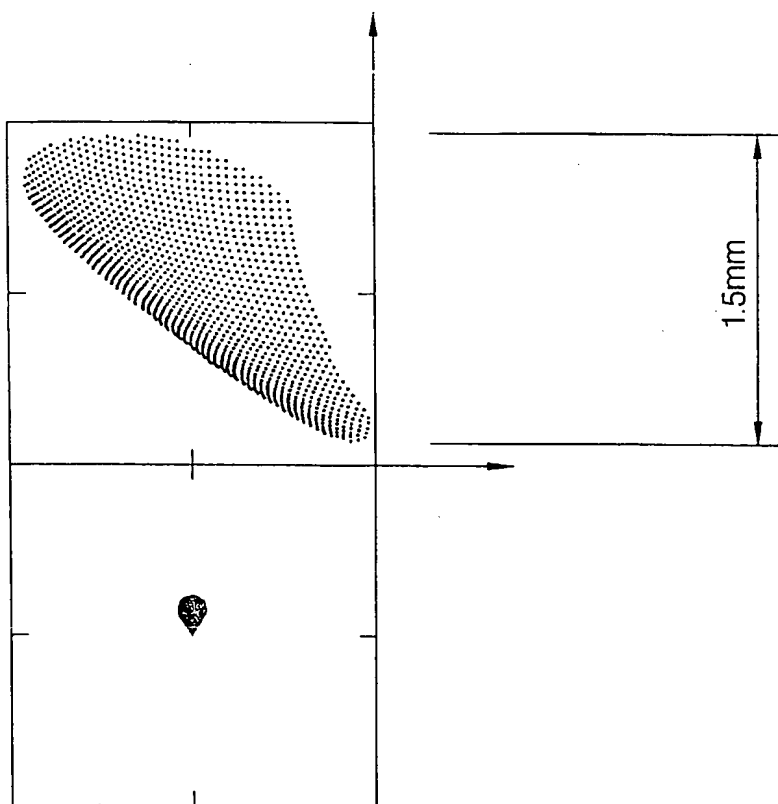


Fig.12.1

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Fig.13

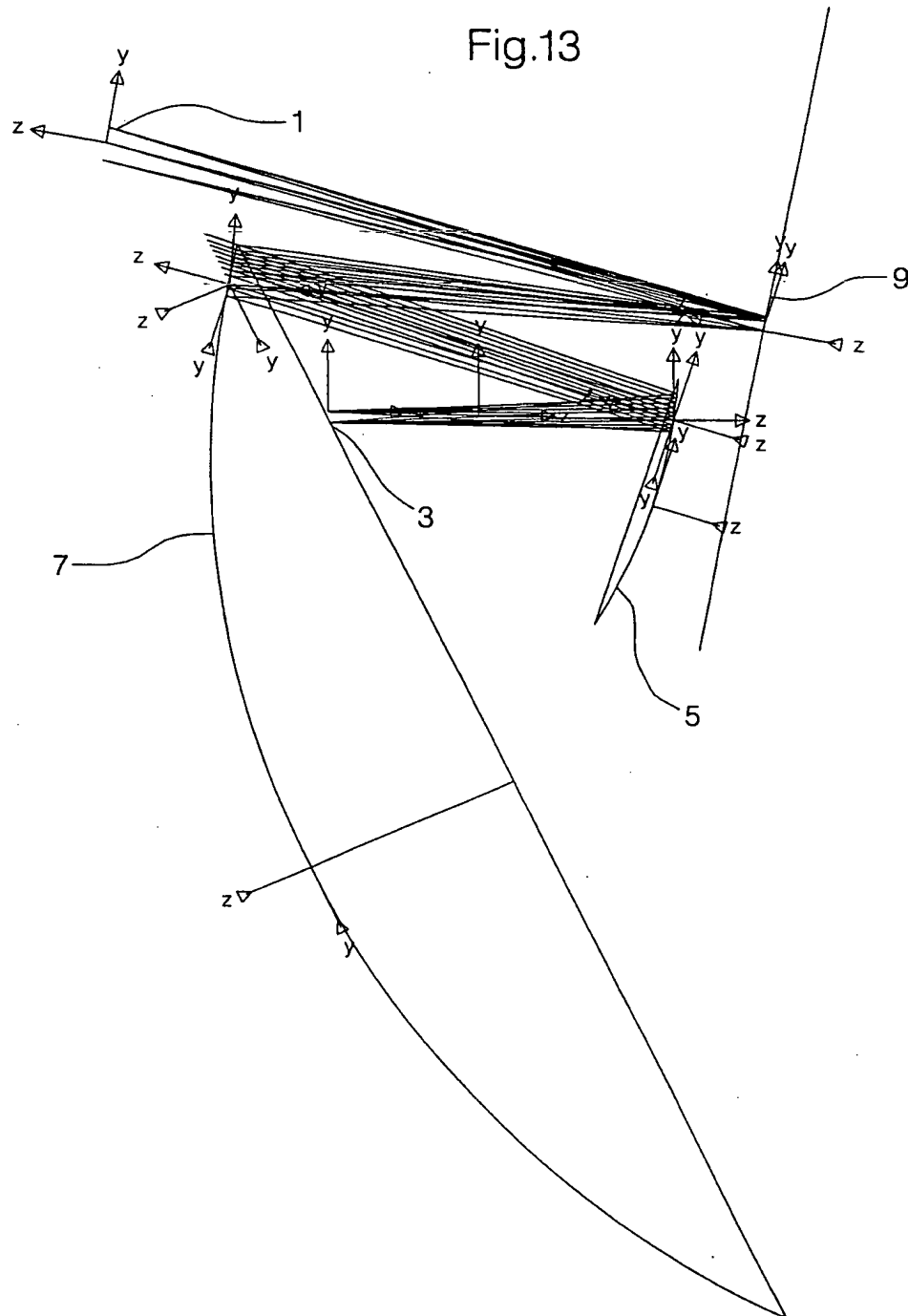


Fig.13.2

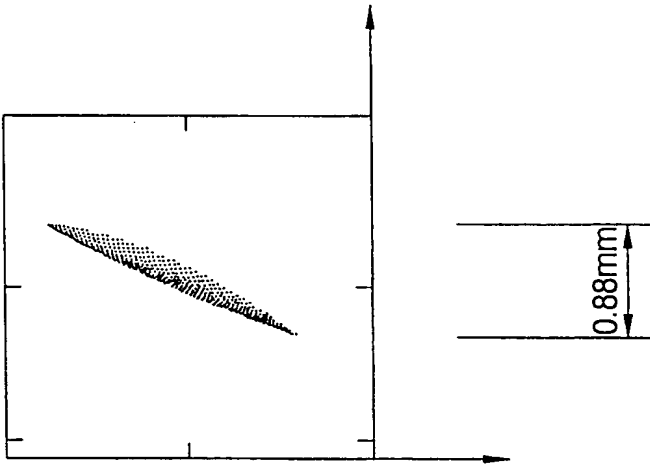
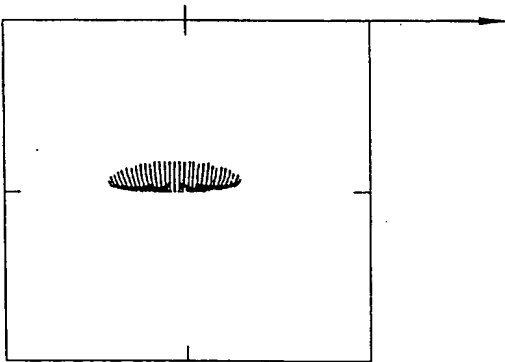


Fig.13.1



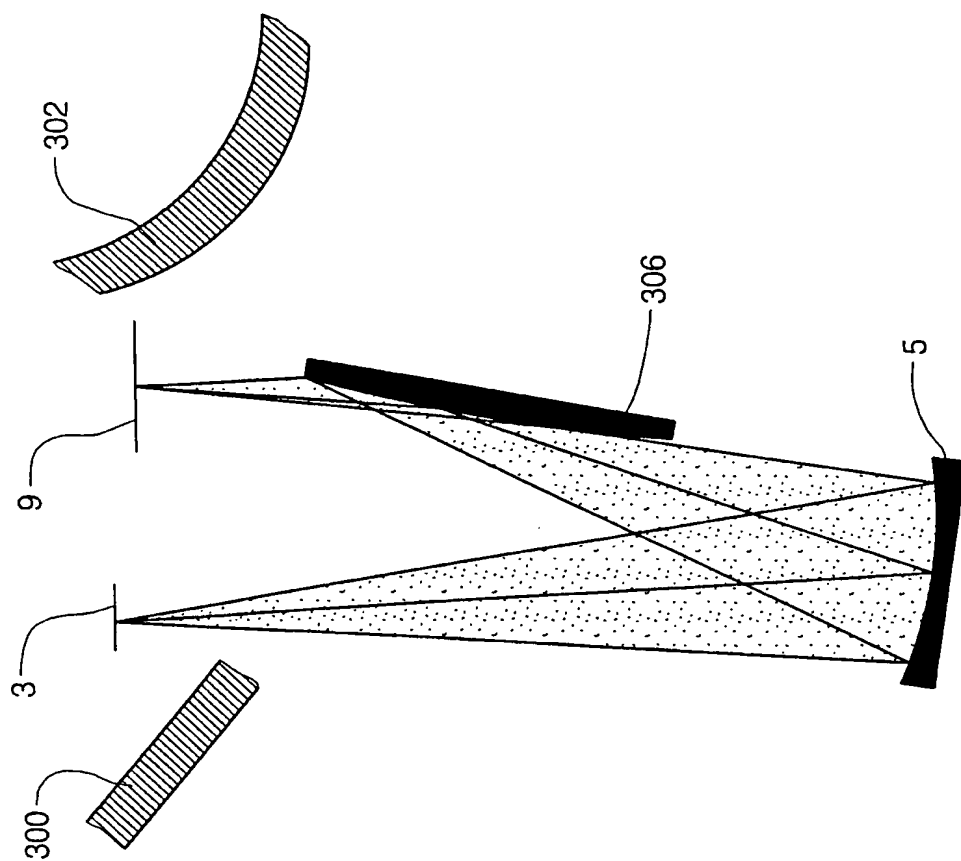


Fig.14

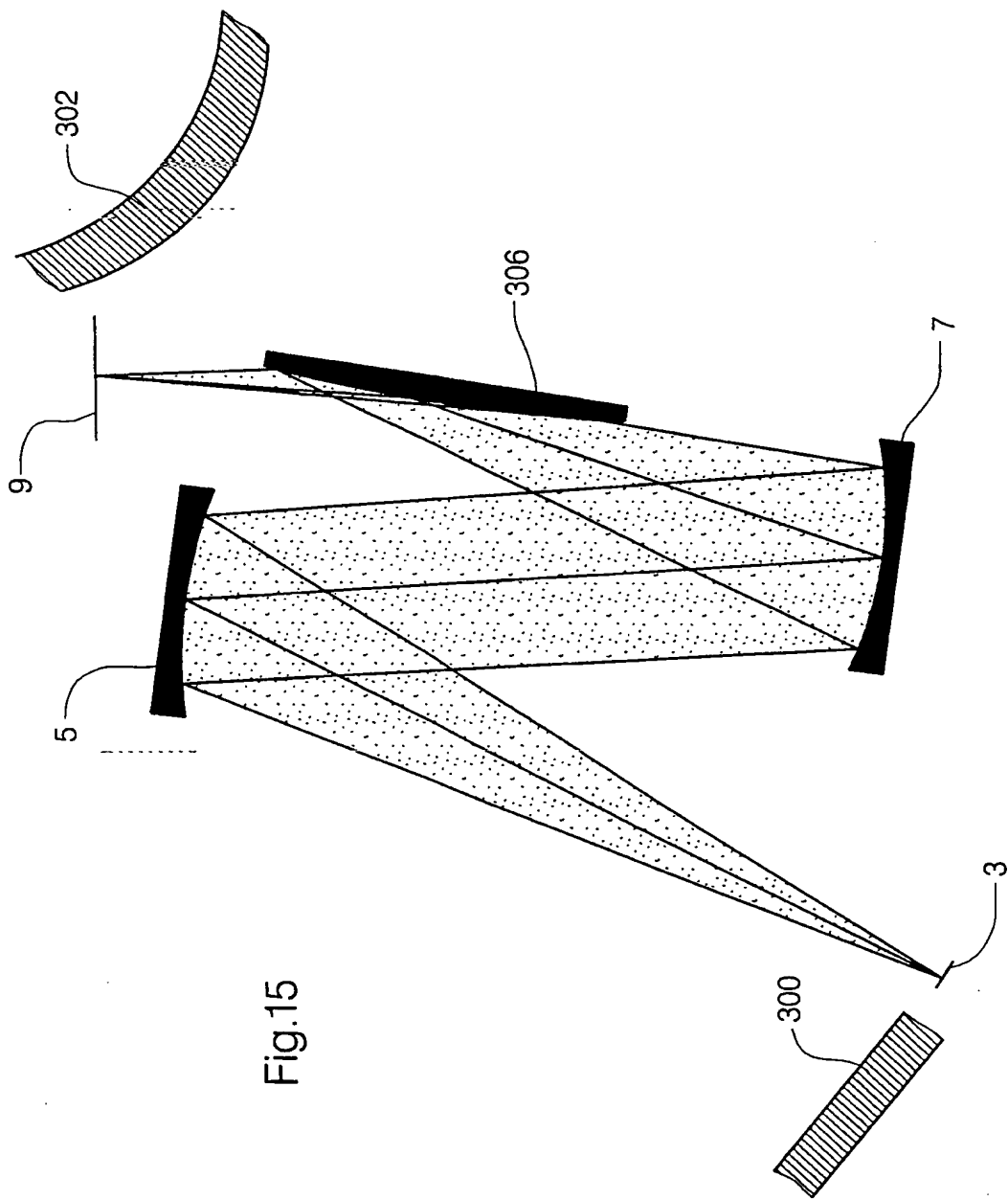
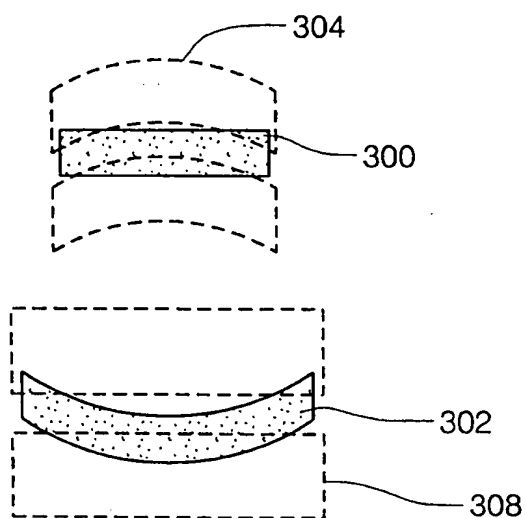
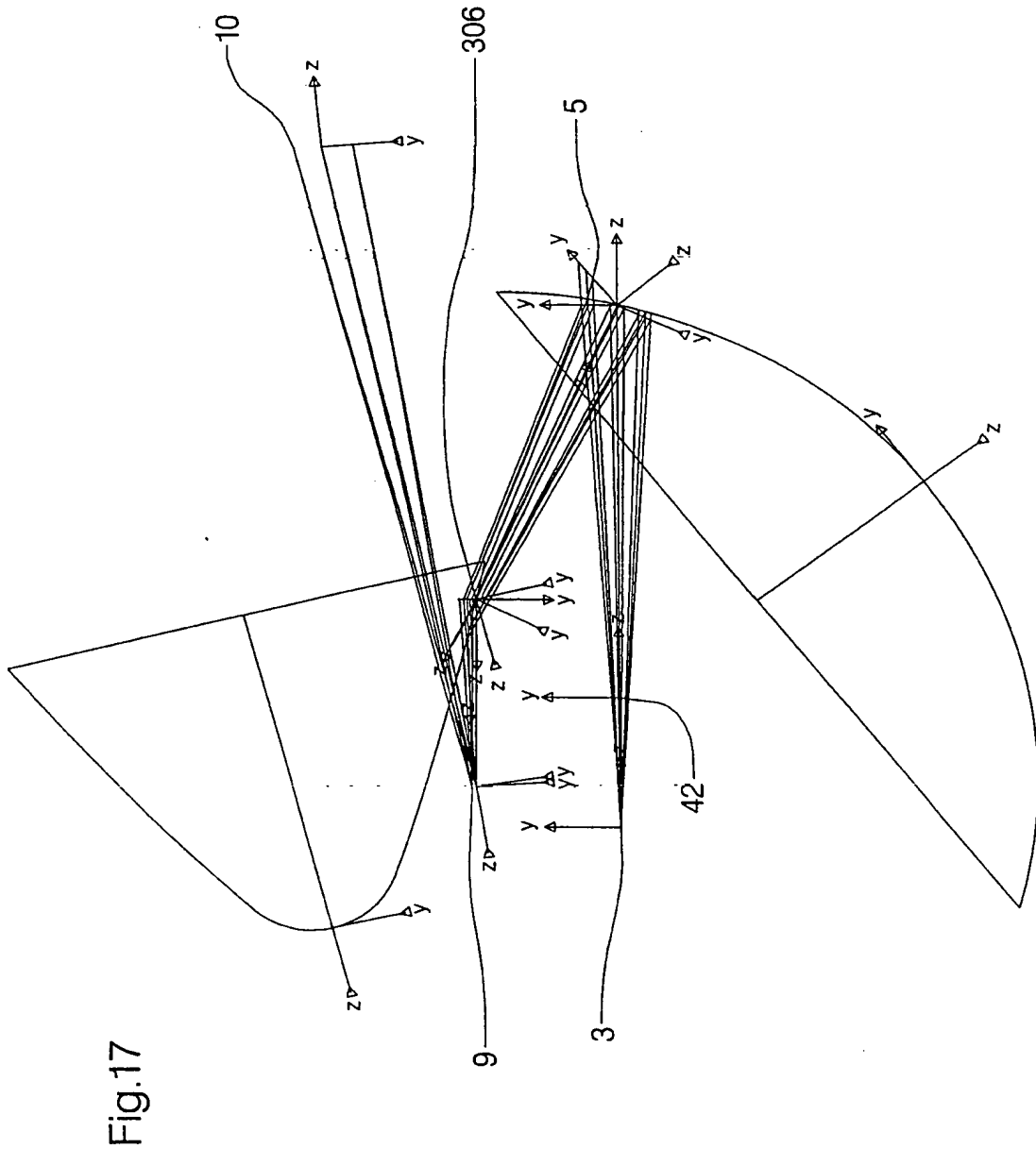


Fig.16

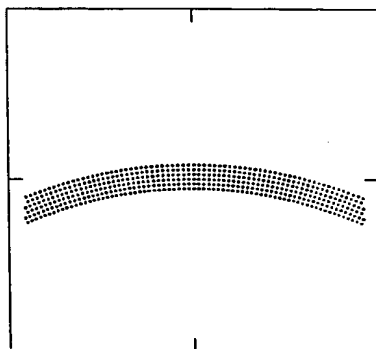






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Fig.17.1



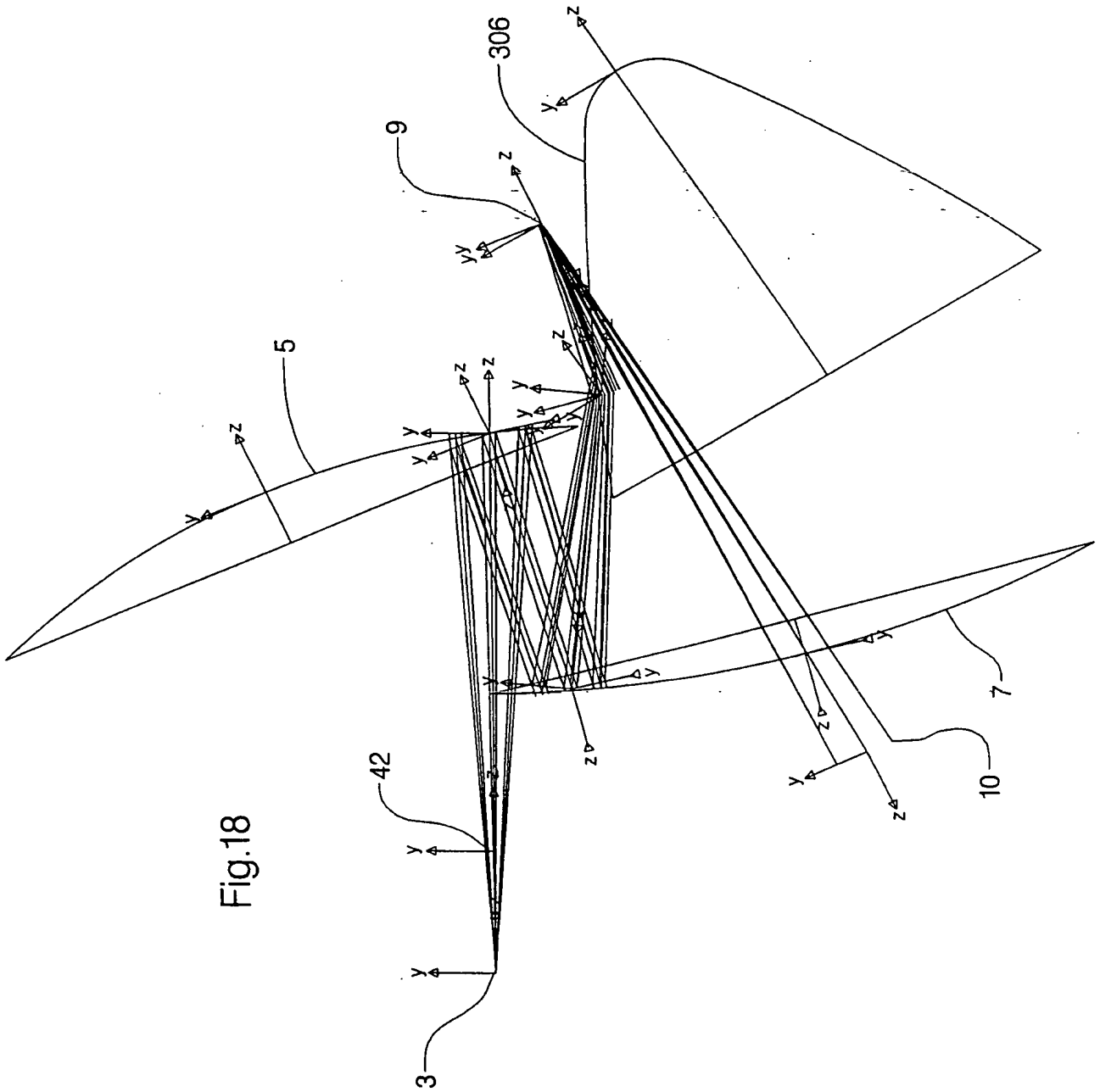
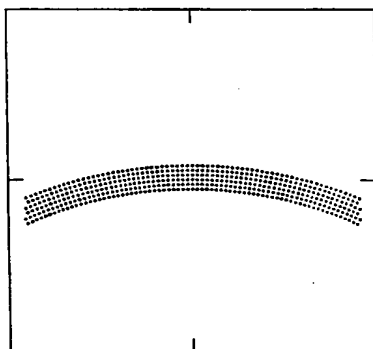


Fig.18

Fig.18.1

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(71) Applicant (for all designated States except GB, IE, JP, KR, US): **CARL ZEISS [DE/DE]; D-89518 Heidenheim (DE).**

(71) Applicant (for GB, IE, JP, KR only): **CARL-ZEISS-STIFTUNG trading as CARL ZEISS [DE/DE]; D-89518 Heidenheim (DE).**

(72) Inventors; and

(75) Inventors/Applicants (for US only): **ANTONI, Martin [DE/DE]; Brunnenstrasse 19, D-73430 Aalen (DE).**

**ESCUDERO-SANZ, Isabel [ES/NL];** Sytwinde 15, NL-2631 GP Nootdorp (NL). **SINGER, Wolfgang [DE/DE];** Egerlandstrasse 45, D-73431 Aalen (DE). **WANGLER, Johannes [DE/DE];** An der Reute 15, D-89551 Königsbronn (DE). **SCHULTZ, Jörg [DE/DE];** Bohlstrasse 29, D-73430 Aalen (DE).

(74) Agent: **DR. WEITZEL & PARTNER;** Friedenstrasse 10, D-89522 Heidenheim (DE).

(81) Designated States (national): **JP, KR, US.**

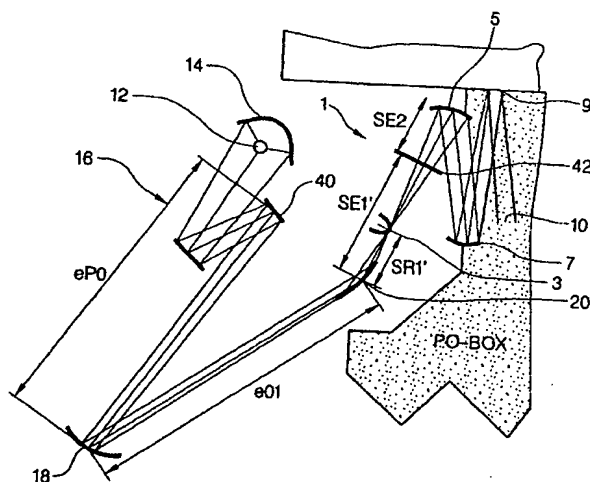
(84) Designated States (regional): **European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).**

Published:

— with international search report

(88) Date of publication of the international search report:  
**8 November 2001**

(54) Title: **MULTI MIRROR SYSTEM FOR AN ILLUMINATION SYSTEM**



(57) Abstract: The invention relates to a multi-mirror-system for an illumination system, especially for lithography with wavelengths  $\leq 193$  nm comprising an imaging system, wherein said imaging system comprises at least a first mirror (5) and a second mirror (7); an object plane (3); an image plane (9), wherein the imaging system forms an image of the object; an arc-shaped field in said image plane (9), whereby the radial direction H in the middle of the arc-shaped field defines a scanning direction. The multi-mirror-system is characterized in that at least said first mirror (5) and said second mirror (7) of said imaging system are arranged in the optical path of the imaging system in such a position and having such a shape, that the edge sharpness of the arc-shaped field in the image plane is smaller than 5 mm, preferably 2 mm, most preferably 1 mm in scanning direction.

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## INTERNATIONAL SEARCH REPORT

International Application No

PCT/EP 00/07258

## A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 G03F7/20

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 G03F G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ, WPI Data

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 572 659 A (OMATA TAKASHI) 25 February 1986 (1986-02-25) column 1, line 12 - line 48 column 2, line 18 -column 3, line 3 column 3, line 57 -column 4, line 23 figures 1-6,9	1-3,27
A	---	30,32
X	US 5 677 939 A (OSHINO TETSUYA) 14 October 1997 (1997-10-14) column 22, line 10 -column 26, line 29 figures 5,6,11-14,21 ---	15,29-32
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☒ Further documents are listed in the continuation of box C.☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

18 December 2000

Date of mailing of the international search report

02.02.01

Name and mailing address of the ISA

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# INTERNATIONAL SEARCH REPORT

International Application No

EP 00/07258

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	<p>US 5 581 605 A (TANITSU OSAMU ET AL)  3 December 1996 (1996-12-03)  column 1, line 11 -column 2, line 22  column 3, line 65 -column 6, line 15  column 17, line 35 -column 18, line 43  figure 28</p> <p>-----</p>	15,29-32

# INTERNATIONAL SEARCH REPORT

International application No.  
PCT/EP 00/07258

## Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:  
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:
3. ☐ Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

## Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☒ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

### Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.
- ☒ No protest accompanied the payment of additional search fees.



FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. Claims: 1-14,27,28; 30-32 (part)

Multi-mirror system arranged to form an arc-shaped image field with a predetermined edge sharpness.

2. Claims: 15-26,29; 30-32 (part)

Multi-mirror system arranged to form an arc-shaped image field and comprising a normal incidence mirror and a field forming component.

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/EP 00/07258

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